Robotics Research Technical Report

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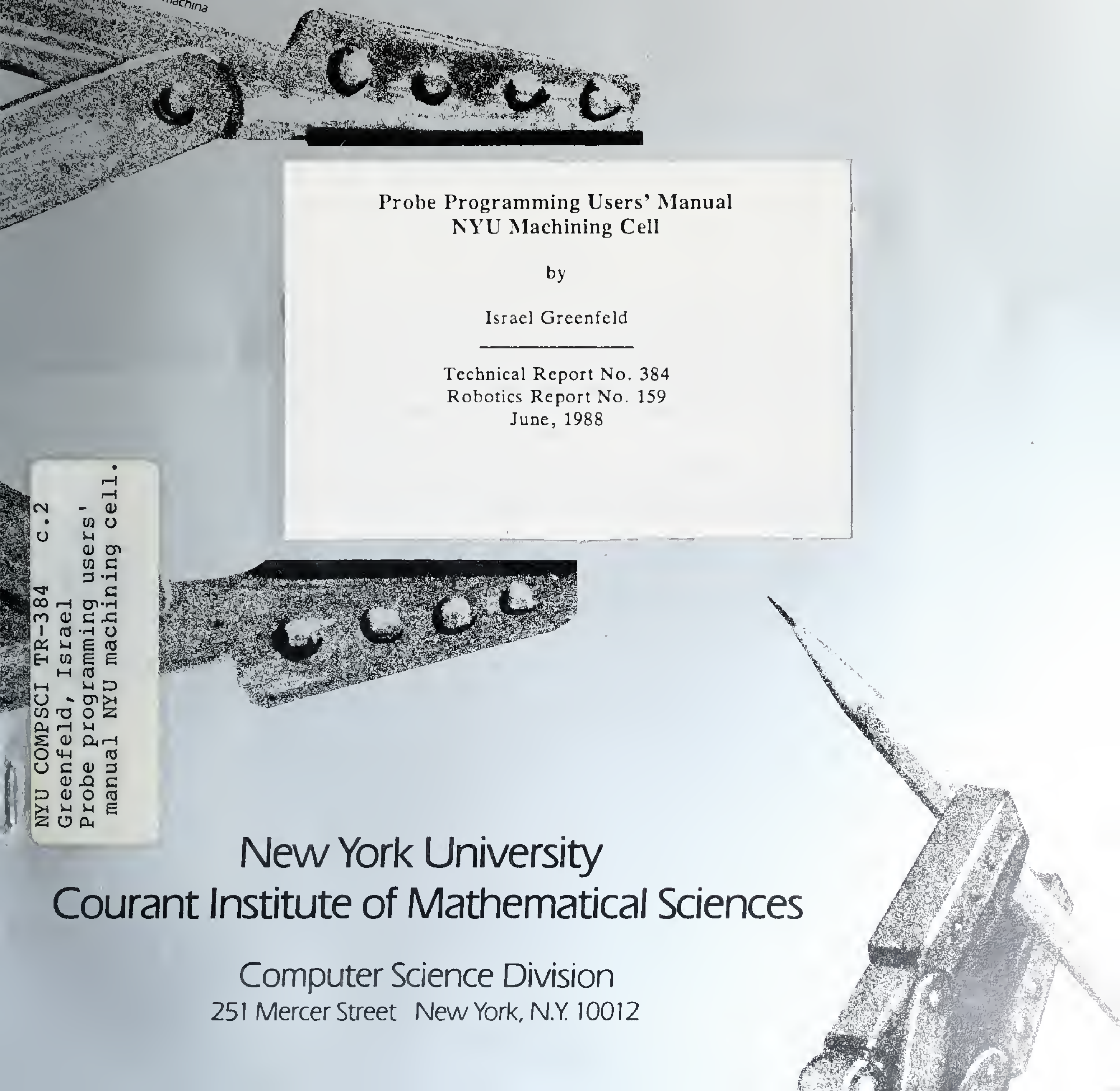

Probe Programming Users' Manual
NYU Machining Cell

by

Israel Greenfeld

Technical Report No. 384
Robotics Report No. 159
June, 1988

NYU COMPSCI TR-384 c.2
Greenfeld, Israel
Probe programming users'
manual NYU machining cell.

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Courant Institute of Mathematical Sciences

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Work on this paper has been supported by Office of Naval Research Grant N00014-87-K-0129 National Science Foundation CER Grant DCR-83-20085, National Science Foundation Grant subcontract CMU-406349-55586, and by grants from the Digital Equipment Corporation and the IBM Corporation.

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NYU Machining Cell

Version I

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Israel Greenfeld

ABSTRACT

This users' manual describes the concepts and operation of a touch probe on a machine tool, using cadcam programming techniques. The system was developed as a component in the autonomous machining cell project in New York University. The basic concept of the system is in-cycle-gauging of machined and pre-machined parts, with the machine tool serving in the function of a coordinates measurement machine, the advantage being production and inspection on the same machine with the same setup.

The system enables the design of a probing cycle on the cadcam model of the part, the execution of the probing cycle and the preparation of quality inspection reports. A special feature is the ability to localize a misaligned part using sparse point data supplied by the probe.

The system is intended for use by students and research staff at the NYU Robotics Laboratory, and may also serve as an outline for future implementation of new applications involving the use of the programming tools and techniques associated with the machining cell.

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1 Introduction

This users' manual describes the concepts and operation of the Renishaw MP9 touch probe on a machine tool, using programming facilities developed in NYU on the cadcam package Anvil-5000. The system enables In-Cycle-Gauging of mechanical parts. The programming and operational environment is unique to the NYU - Robotics Laboratory installation, and is part of its Autonomous Machining Cell project. The system may be adapted to other installations with appropriate changes.

The manual is intended for use by students and research staff who wish to use probing techniques in conjunction with research in autonomous intelligent manufacturing. Typical applications range from on-line in-process dimensional inspection, calibration of workholding devices and gages, spatial location of parts and statistical data gathering. Previous knowledge of the operation of Anvil-5000 and the machining cell is recommended as a prerequisite for this manual. The use of the equipment requires authorization from the NYU -Robotics Laboratory staff.

The manual is arranged in a large scope, to include many examples of programs and applications. Two reasons account for that: First, the suppliers' documentation is sometimes incomplete or incomprehensible. Second, the programming environment used, namely the cadcam utilities and the post-processor, are not standard and require some specific on-site training, which I hope this manual will provide. This kind of knowledge will be essential for future developments in the machining cell environment.

Other supporting documentation is listed in the References section of this manual, and includes the machine tool and controller operators' manuals, Anvil-5000 manuals, the probe user's guide and the post-processor user's manual. Additional information may be found on a few site specific guides that describe the cell operation.

On This Manual:

Chapter 2 *Overview* and chapter 3 *Probe Functions* describe the basic technical background of the machining cell, and in particular the probe.

Chapter 4 *Definition of Variables* and chapter 5 *Basic Function Calls* cover the low level and medium level programming of the probe, which are the supplier's original macros and the post processor NC macros, respectively. These chapters are very technical and are not essential for the high level programming. They will be needed for adding new probe utilities.

Chapter 6 *Programming in Anvil-5000* and chapter 7 *Application to Sample Cases* include step by step instructions for programming the probe from within the cadcam, and a few examples of applications.

Chapter 8 *Programs Structure and Installation*, chapter 9 *Deficiencies and Future Enhancements* and the appendices describe the programming environment in Anvil-5000 and contain excerpts from the programs for reference.

2 Overview

2.1 The Machining Cell

The NYU Autonomous Machining Cell project is built around a machining center that is supported by a cadcam system, a computer network and an operating environment. In the near future the cell will be enhanced with robotic, vision and expert systems. The current configuration includes the following components:

Kitamura MyCenter 1/485 machine tool [1-3].
Fanuc 10M controller [4,5].
Sun 3/60C color workstation, networked to the lab.'s Ethernet [6-8].
MCS Anvil-5000 cadcam software [9].
Renishaw MP9 touch probe [10,11].
Synermation MFNC01 post processor software [12].
Cell operational environment software [13,14].
Cadcam cell utilities.
Users' libraries.

This configuration provides the basic advanced design and manufacturing capabilities of the cell that are currently available. To demonstrate these capabilities let us consider a part's design and manufacturing using the cell. Typically the following steps will be taken: Part design on the cadcam system using wireframe, surfaces and solids construction methods. Design of machining tool paths on the cadcam using the part's geometrical model. Creation of a high level language machining output file, in the format of APT, Compact, Clfile or Clprint. Translation of the output file into the Fanuc controller's machine code, using the semi-custom post processor. Using the cell operating environment to send machining files to the machine tool. Probing the part on the machine tool, using a program prepared on the cadcam, and reading results back to the Sun computer. These results may serve for a quality control report or for part location and transformation.

2.2 The Probe System

Refer to figure 2.1 for the Renishaw MP9 probe system layout. The probe provides the machine tool with a touch sense, supplying data for automatic update of work coordinates and tool offsets, at any stage except when cutting. The probe operating cycles, also known as In-Cycle-Gauging, include tool setting, tool wear monitoring, workpiece identification, workpiece set up and workpiece inspection.

The probe is shank mounted and is stored in the machine's tool magazine. It is automatically loaded on the machine spindle for a gauging cycle. It is switched on by spindle rotation, and uses an infrared communication system to send results to the machine tool controller. As the probe is driven around the machine, using the machine axes of motion, the control continuously monitors the stylus ball position. The probe is a highly repeatable omni-directional switch, which fuctions in the X, Y and Z directions. On contact with a surface the stylus deflects and a trigger signal is generated. The true rather than the theoretical surface position is therefore recorded in the machine tool control. A command stops machine motion within the limits of the stylus travel. The probe uses a two step touch cycle, a first rapid move to locate a surface and a second slow move to measure it accurately.

A package of machine tool macros supplied with the probe controls the probe functions. These macros are accessible through the regular machine programming of the Fanuc controller as special G and M codes. New macros may be written for site specific applications, using the macro programming language of the Fanuc controller. An example of a typical application may be driving the probe in a vector motion (combined axes motion) to facilitate gauging of slant or sculptured surfaces.

The accuracy of the probe depends on the accuracy of the machine tool , the calibration of the probe, the approaching speed and direction and on other factors. In the NYU installation a repeatability of 0.0002" and an accuracy of 0.0005" are estimated under favorable conditions. This level of accuracy may enable gauging of a large variety of mechanical parts, but excluding high precision parts.

In-Cycle-Gauging is an essential feature in the implementation of the autonomous manufacturing cell. A demonstrative example is the manufacturing of one-of-a-kind parts. This kind of production entails flexible fixturing systems and requires in-line quality control. The position of the part on the machine tool table will typically be inaccurate. In-Cycle-Gauging provides inspection and correction in a single set up and supplies the spatial position data needed for part localization.

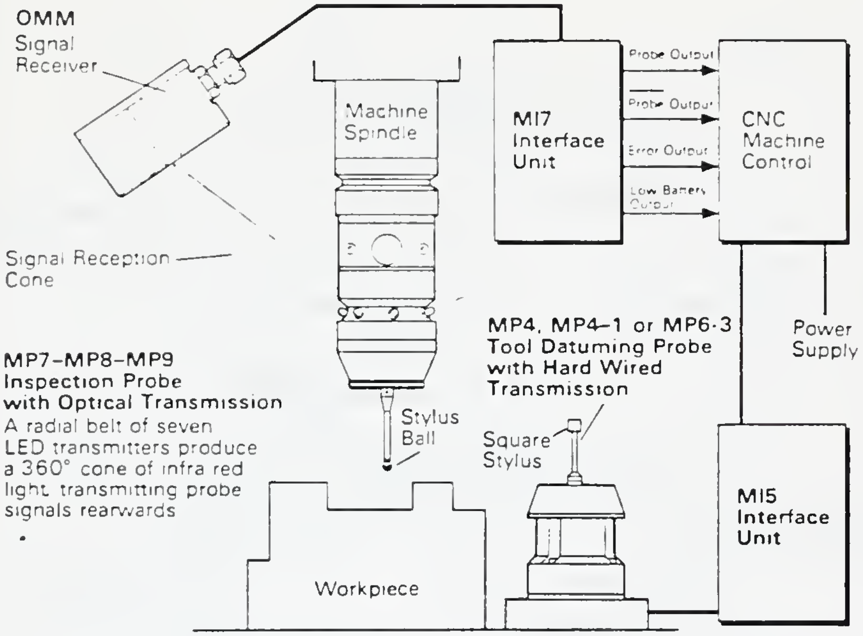

Figure 2.1: The Renishaw MP9 Touch Probe System

3 Probe Functions

This chapter describes the probe functions in terms of their intended use.

3.1 Terminology

Refer to figure 3.1 for a block diagram describing the levels of programming the probe.

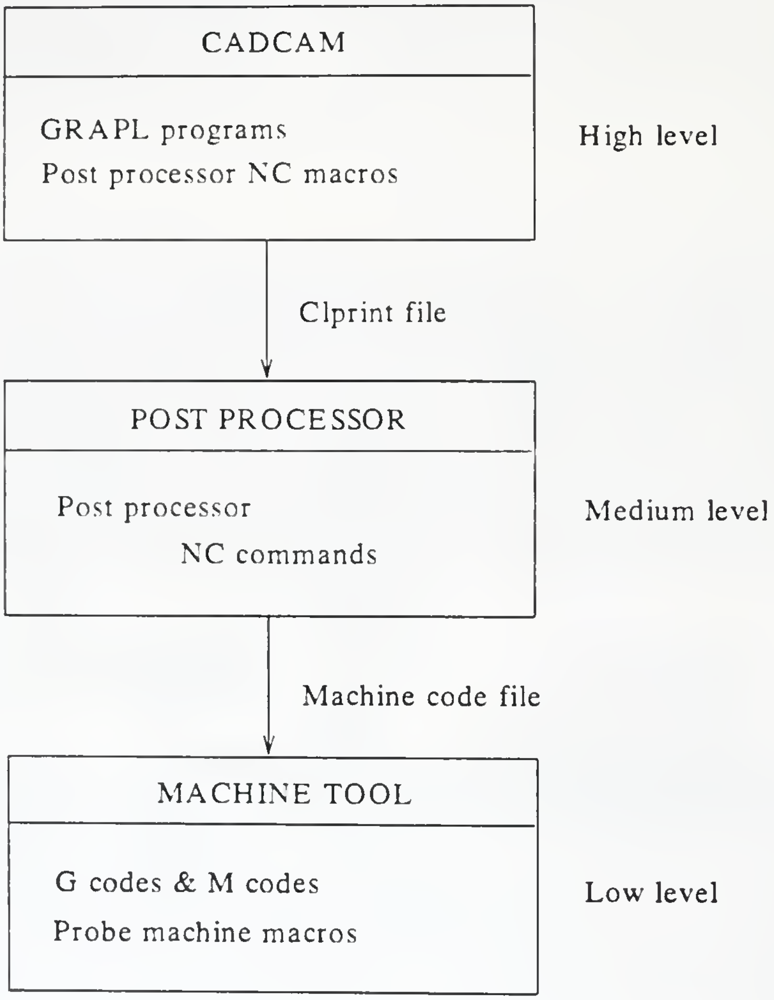

Figure 3.1: Probe Levels of Programming

The probe functions are arranged in three programming levels: Low, medium and high. The basic probe operations are driven by the *machine macros* supplied by Renishaw. They constitute the *low level* programming environment. The macros are called by *G codes* and *M codes* unique to the probe. The probe may be programmed manually using these codes, though it is fairly difficult. The *medium level* programming uses *post-processor commands* which are in a *Clprint* NC output file format. The *high level* programming uses the cadcam *GRAPL* and *post-processor NC macros* to produce groups of medium and low level machine commands that pertain to a specific probe function.

Refer to fig. 3.2 for the definition of the basic geometrical features that the probe system addresses.

notes:
- Gauging direction is only along the main axes of travel of the machine tool.
- Web, pocket and XY surface are posible in either the X or Y directions.
- External corner and internal corner may be in any of the four quadrants, and only in the XY plane.

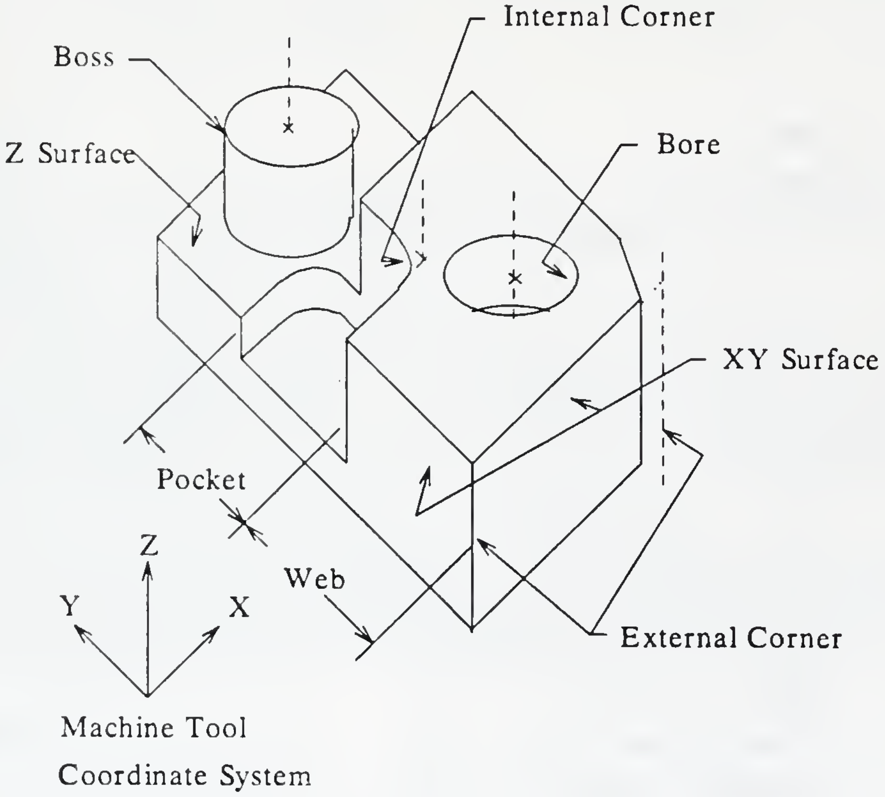

Figure 3.2: Definition of Part's Features for Probing

Refer to figure 3.3 for definitions of the segments and attributes of a representative probe path. An explanation via a typical scenario follows.

Description of a Typical Probe Path:

A *probe loading* sequence is invoked and the probe is loaded onto the machine tool spindle. The probe *length offset* is activated to compensate for its calibrated length, and the probe is switched on by a spin of the spindle. The probe is then moved around using *protected positioning* motion, which guarantees a prompt stop of the machine in case an obstacle is encountered. The probe is firstly moved with *rapid feedrate* to a *clearance plane*, which is a Z plane defined above the locally highest feature of the workpiece. Then it is moved within the clearance plane and positioned above the *start point*, using *rapid feedrate*. The start point is specified as a signed distance *delx, dely & delz start* from a reference *indicated point* on the workpiece. Then the probe plunges down from the clearance plane to the start point using

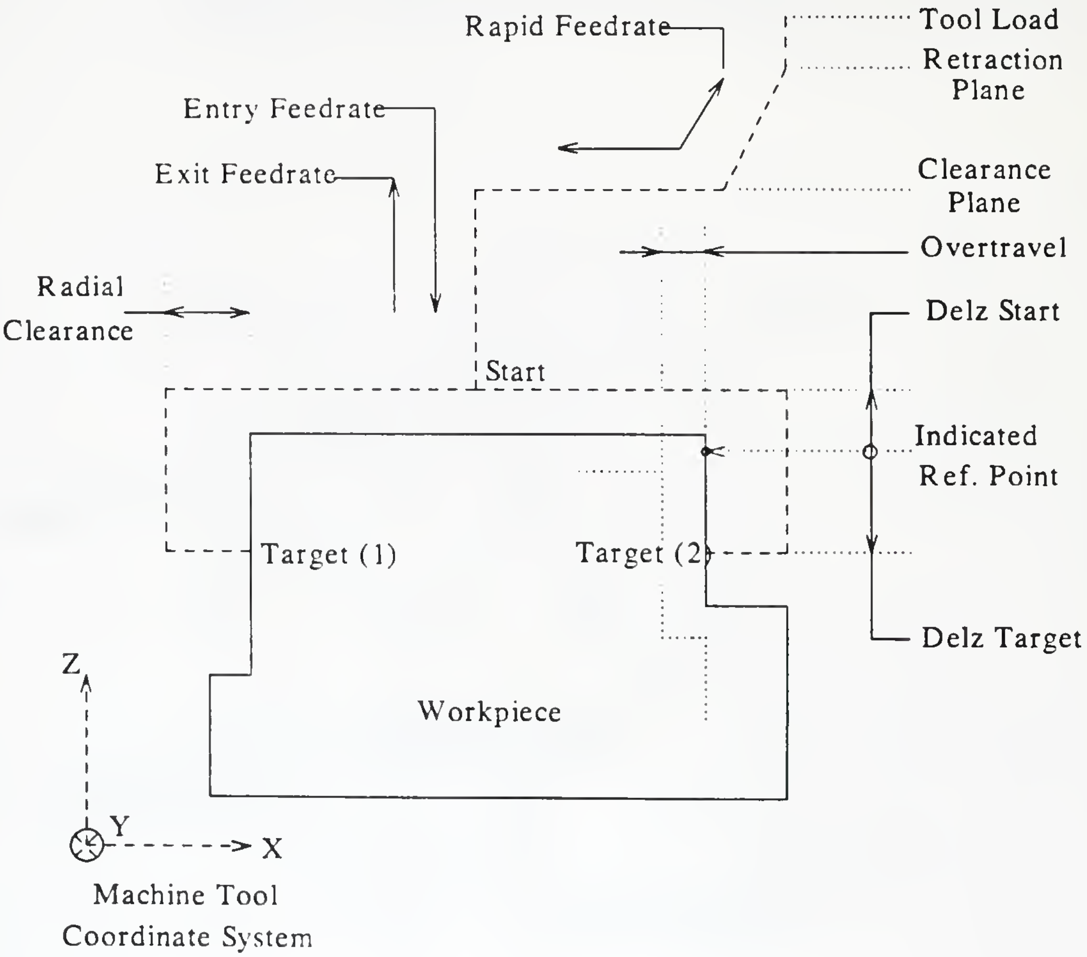

Figure 3.3: Definitions of Probe Path Segments and Attributes

entry feedrate.

The *probe cycle* is then commanded, and the probe gauging cycle starts. The probe moves towards the *target point(s)* in the current Z depth or, in some cases, moves down to the Z depth of the target, specified as a signed distance *delz target* from a reference indicated point. The probe moves towards the target until touch occurs or until the *overtravel* amount specified is exceeded. A probe cycle may simply move the stylus towards a single surface (as in probing a Z surface and an XY surface), or it may move the stylus towards a few surfaces - up to four (as in web, pocket, bore ,boss and corners). In probing a protruding feature, such as a boss and a web, the probe moves horizontally away from the feature's edge to a *radial clearance* specified , and then plunges down in Z.

Upon the completion of the probe cycle, the probe moves upwards in Z, back to the clearance plane, using *exit feedrate*. Then it moves within the clearance plane (which may be redefined) towards a new probe cycle start point, or retracts upwards to a *retraction plane* and is backloaded on the tool magazine.

The probe gauging and calibration results may be stored in the machine tool *offset registers* and *macro variables*, for use in susequent machining or probing operations. *Tool offset* registers and *work offset* registers may be updated to compensate for tool wear and workpiece misalignment, respectively, and to be used later. All the gauging results and updates may be printed out to the host computer for the preparation of an inspection report and for calculating coordinate systems' transformations if needed.

3.2 Basic Functions

This paragraph describes the low level probe functions. Refer to fig. 3.4 for the description of probe paths of the various basic functions. For more details refer to the Renishaw Probe User Guides [10,11].

The basic probe functions are categorized into four groups: Loading and motion functions, Calibration functions, Datuming functions and Measuring functions. The loading and motion functions are used for probe startup and rapid positioning. The calibration functions are used for periodic calibration of the probe length, stylus side offset from the spindle center and triggering envelope. The datuming functions are used for setting and updating work coordinate systems on the machine tool. The measuring functions are used for gauging features on a part and returning results or updating tool and work offsets.

A typical function starts the probing cycle at a position near the feature to be gauged (denoted by *s* on fig. 3.4), and performs a motion towards the target (denoted by *t* on fig 3.4). The motion is produced by the probe machine macros. The start position is reached by a sequence of protected positioning motion programmed by the cadcam (described later).

3.2.1 Probe Switching and Positioning

Switching (M119)

After being loaded onto the spindle the probe is switched on and oriented by a short spin of the spindle. It is automatically switched off a few minutes after the last triggering has occurred. A proper tool offset should be activated before proceeding with positioning.

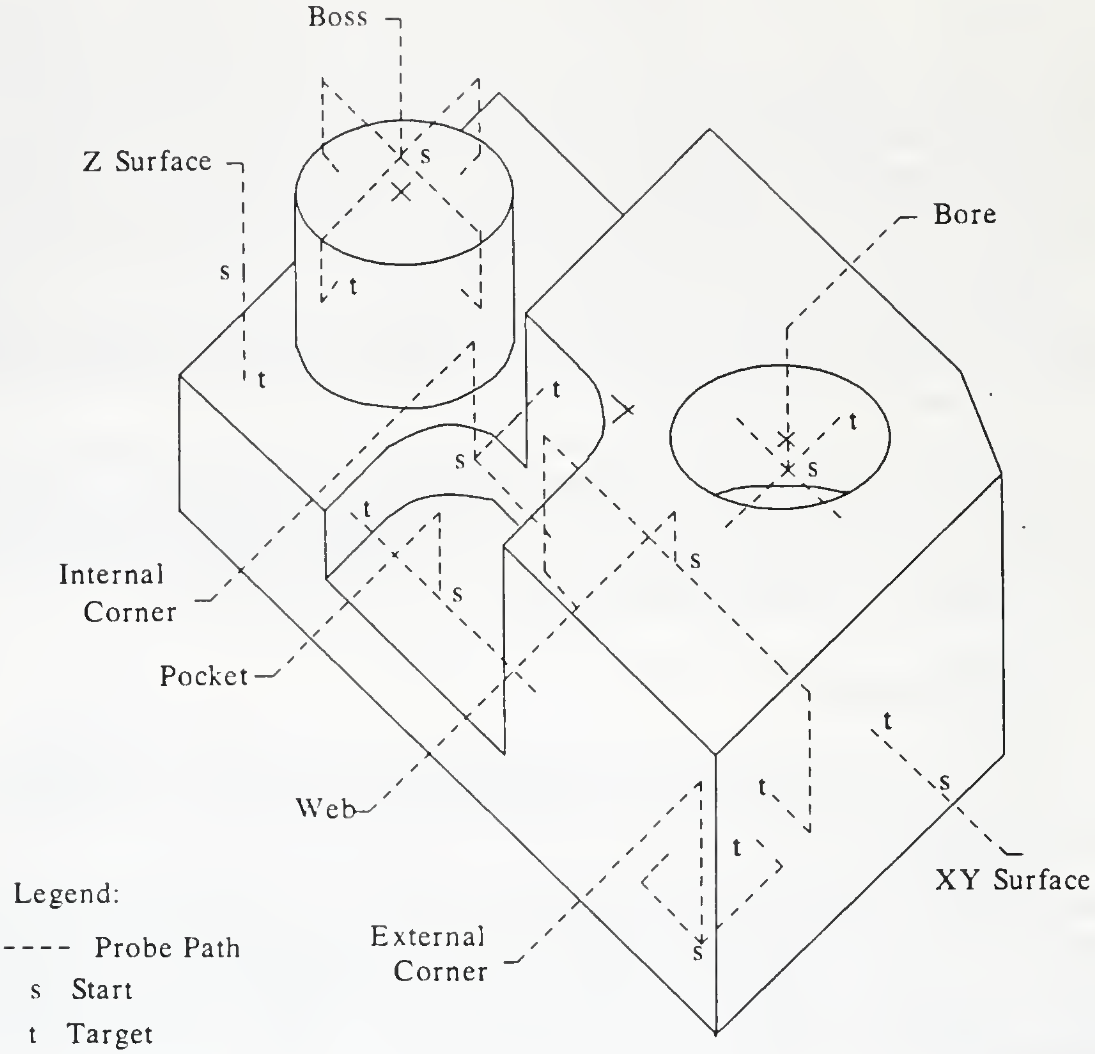

Figure 3.4: Probe Paths for Various Functions

Protected Positioning (G101)

The probe is moved along the machine tool axes using a protected positioning command. This mode is used for rapid positioning of the probe prior to a gauging cycle. Protected positioning uses a linear interpolated motion towards the specified position, at the specified feedrate. If an obstacle is encountered before reaching the specified position, the machine stops and an alarm message is issued. The feedrate is modal.

3.2.2 Calibration Functions

Probe Center (G106)

Also called *datum in a bored hole*. This function measures the stylus side offset relative to the spindle center, and stores the offset value in a machine macro variable to be used throughout the probe cycles. The offset has a separate value for X and for Y. The calibration is done on a bore larger than 20 mm. The exact size of the bore is not important. The probing is performed shortly after the boring, witout moving the X and Y axes. The start position should be within 2.5 mm from the bore's centerline, and at the Z height of the gauging.

Probe Diameter (G105)

Also called *datum in a ring gauge*. This function measures the effective stylus ball radius (triggering envelope) in the four horizontal directions. The results in +X, -X, +Y and -Y are stored in machine macro variables, to be used throughout the probe cycles. The calibration is done on a bore larger than 25 mm. The exact size of the bore should be known accurately, and therefore a ring gauge is preferred. A work offset may be updated with respect to the ring center. The start position should be within 10 mm from the bore's centerline, and at the Z height of the gauging.

Probe Length (G107)

Also called *datum in Z axis*. This function measures the probe length offset with reference to any known datum feature such as a gauge, a top of a vise or a top of a workpiece. The offset is then stored in a specified tool offset register on the machine for use in all subsequent probe cycles. The position of the datum feature should be known accurately if an absolute offset is desired. If a top of a workpiece is used as a datum, a relative offset would be obtained and may be used for this workpiece only. A tool offset may be updated with respect to the datum feature. The start position should be approximately 5 mm above the feature to be gauged, and at the X and Y position of the gauging.

3.2.3 Datuming Functions

Internal Corner (G111)

This function will set a datum relative to an internal corner of a part. The datum may be referred to a remote point. A work offset to be updated should be specified. If the offset specified is the current work coordinate, the current work offset will be updated. If a different work is specified, it will be updated with the offset value of the current work coordinate *plus* the error measured. The work offset updated may be used for susequent machining and probing programs. The start position should be at a convenient location away from the corner (not necessarily the same distance in X and Y), at the Z height of gauging. The function will work in any quadrant.

External Corner (G112)

See explanation in *internal corner*.

3.2.4 Measuring Functions

Web/Pocket (G110)

This function will gauge the width of a pocket or a web, in either the X or Y direction. If a work offset is specified the centerline of the feature may be determined and the offset is updated. If a tool offset is specified the radial offset may be updated. The offsets may be used by subsequent machining programs. The width size error may be stored in one of the tool offset registers for later use or output. The error may be controlled by a tolerance. For a web the start position is above the the web's surface near the centerline. For a pocket the start position is at the Z height of gauging. The direction of the gauging, either X or Y, should be specified.

Bore/Boss (G119)

This function will gauge the diameter of a bore or a boss. If a work offset is specified the centerline of the feature may be determined, and the offset may be updated. If a tool offset is specified the radial offset may be updated. The diameter size error may be stored in one of the tool registers. The error may be controlled by a tolerance. The error and the offsets may be used later. For a boss the start point is above the boss's surface near the centerline. For a bore the start point is at the Z height of gauging.

Z Surface (G118)

This function measures the position of a surface in the Z direction and stores the error in an offset register. The error may be controlled by a tolerance. Either the tool length offset or the work offset (but not both) may be updated if specified. The error and the offsets may be used later. The start position may be at any location above the surface.

XY Surface (G113)

This function measures the position of a surface in either the X or Y direction and stores the error in an offset register. The error may be controlled by a tolerance. Either the tool radial offset or the work offset (but not both) may be updated if specified. The error and the offsets may be used later. The start point is either at the Z height of gauging, or above the edge of the surface, depending on the setting of the command (the former method is used by the cadcam programming).

3.3 Advanced Functions

The advanced functions include the high level utilities used to program the probe from the cadcam. The basic functions are sub-components of these functions. Some advanced functions are operated from the operating system rather than from the cadcam, and therefore will be detailed in the *NYU Machining Cell Users Manuals* [13,14].

3.3.1 Startup

This function is used to invoke a probe startup sequence. It includes the following steps: Loading the probe from the tool magazine to the spindle. Switching on and orienting the probe with a short spin of the spindle. Activating the probe's length offset. And, moving the probe rapidly to the retraction plane and then to the clearance plane.

3.3.2 Positioning

This function is used to locate the probe at a desired gauging cycle start point. The basic functions all start at a start point (denoted by *s* on figs. 3.3 and 3.4) close to the feature that is to be gauged. In a process that contains many gauging cycles the probe should be positioned at a new start point for each cycle. This positioning includes the following steps: Moving rapidly from a retraction plane to a clearance plane. Moving rapidly within the clearance plane to a location above the start point. Plunging down to the start point at an entry feedrate. Allowing for the probe cycle to execute. Moving upwards back to the clearance plane at an exit feedrate. And, moving rapidly to a new location within the clearance plane, or retracting rapidly to the retraction plane. Both figs. 3.3 and 3.4 show this sequence. All the motion parameters are controlled by modals' settings.

3.3.3 Spatial Location of Parts

This function is used to localize in 3-D a misaligned workpiece attached to the machine table. The procedure includes the following steps: The workpiece is probed, using Z surface and XY surface gauging cycles, at 6 points - 3 on a *primary surface*, 2 on a *secondary surface* and 1 on a *tritary surface*. For a 2-D localization three points suffice. The x, y & z values for each point are used to compute the transformation matrix from the workpiece coordinate system (in which the tool paths are usually given) to the machine tool coordinate system. Finally, the tool paths' output files are transformed and sent to the machine.

The function is currently limited to probing normal planes, extending along the machine's main exes. 3-D transformation requires a 5-axis machine tool. The transformation is done outside the cadcam and uses the *cell operating environment* described in the *NYU Machining Cell Users Manuals*.

3.3.4 Miscellaneous Functions

These functions are also operated in the *cell operating environment* described in the *NYU Machining Cell Users Manuals*. They include commands for a full calibration of the probe, setting work offsets on the machine tool, resetting memory registers, printing out measurements' results, arranging a quality control report, computing a transformation matrix, applying a transformation to a tool path, calibrating the machine tool and others.

Note:

The reader who is interested only in high level programming with the cadcam may skip directly to chapter 6.

4 Definition of Variables

4.1 Probe Variables

The probe variables are used throughout the probe programs. The Modifier symbols are used in the GRAPL program and in the Post-Processor NC macros. The Name symbols are used in the GRAPL program, the PP NC macros and in the probe G codes. The Code symbols are used in the probe G codes only.

Modif.	*Name*	*Code*	*Description*
		X,Y,Z	Target position. Defines the nominal postion of the surface to be gauged.
FEDTO	iz		Incremental depth of target. Defines the total incremental infeed depth in the Z axis, measured from the incoming point. This variable is not used in the cadcam programming, but only with medium level programming.
THICK	l	X,Y	Web / pocket thickness. Defines the width of a web or a pocket in either the X or Y direction. Slant web/pocket may not be used.
DIAMTR	d	D	Diameter of a measured feature. Defines the diameter of a bore/boss to be measured, or a bore / ring gauge used for probe calibration.
ERRNO	m	M	Gauging error memory address. Defines the address of a vacant tool offset register to be used as a memory for probing results. By convention we use registers 21 to 32 for the probe. The error value will be positive for Metal On condition (excessive material - correctable), and negative for Metal Off condition (not correctable).
WOSET	s	S	Work coordinate offset number. Defines the number of the work coordinate system to be addressed (to be updated). No. 1 to 6 correspond to G54 to G59.

OSETNO	t	T	Tool offset register number. Defines the number of tool offset register to be updated with an error value (offset). By convention we use registers 1 to 20.
TLRNCE	h	H	Tolerance of a feature. Defines the tolerance of the dimension of the feature to be gauged. The value will be half the total tolerance.
UPPTOL	u	U	Upper tolerance limit (G113 only). Defines the upper limit for the error, beyond which no updating of the tool offset is done.
RAPTO	r	R	Radial clearance from target. Defines the incremental horizontal position of the start point from the nominal target surface, prior to a Z axis move. The system default is 5 mm.
OVTRAV	q	Q	Probe overtravel. Defines the prove overtravel beyond the nominal position of the target. The system default is 4 mm.
PRTDIM	v	V	Print dimensions option (not available yet). Defines a printing option for dimensions. Option 1 is data only. Option 2 is data and header.
PRTPOS	w	W	Print position option (not available yet). Defines a printing option for positions for G119. Option 1 is data only. Option 2 is data and header.

Note:

Whenever the named variable takes a value of 999 it is ignored by the post processor.

4.2 Cadcam Modal Variables

The cadcam modal variables are set at the GRAPL program and and used by the Post-Processor NC macros to control a few basic machining variables. The values are modal for all probe functions until updated.

Name	*Default*	*Units*	*Description*
FRA	100	IPM	Rapid feed rate used for moving the probe within the clearance plane.
FEN	20	IPM	Entry feed rate used for descending from the clearance plane to the gauge starting point.
FEX	40	IPM	Exit feed rate used for the probe withdrawal from the gauge end point (same as start point) back to the clearance plane.
CCZ	4	INCH	The height in Z of the clearance plane. This value will typically be above the the highest point of the part at the region of gauging.
CRZ	6	INCH	The height in Z of the retraction plane. This will be the probe start and end of measurement process, after or before tool change.
TNO	15		Probe tool number.
TOS	15		Probe tool length offset register.
REG	21		First memory register used to store gauging results. The program increments the current error register m for each new probing cycle that produces an error value.

4.3 Cadcam Current Variables

The cadcam current variables are set in the GRAPL program and used by the Post-Processor NC macros to specify the probe movement from one gauge location to another. The values are redefined for each new probe function.

Name	*Description*
X, Y, Z, RAD	Values of position and radius of indicated features. Position is given in Model Space Coordinates (and therefore does not correspond to a DCS).
X1, Y1, Z1, X2, Y2, Z2	Same as above. Used for two points indicated on web or pocket surfaces.

DELX, DELY, DELZ	Incremental values of the gauging start point with respect to the indicated point.
XS, YS, ZS	Values of the position of the gauging start point. Position is given in Model Space Coordinates.
@PCX, @PCY	Anvil-5000 built in machining variables which specify the current tool position in X and Y. Other builtin variables are available but were not used here. See [9].

5 Basic Function Calls

The following section describes the low and medium level commands and their relationships. A more detailed description of the low level probe functions is contained in the Renishaw MP9 Probe User Guide [10,11]. Each post processor cycle command is followed by the machine code translation. The symbol '^' denotes continuation of the cycle command on the next line. When X, Y or Z values are denoted by *(next)* the values are taken from the incoming point (next GOTO/x,y,z command). The incoming point (next GOTO) itself is never interpreted as a motion command by the post processor. Nevertheless it should always be included in the post processor input lines after the CYCLE command, even if it does not contain any position data for the current probe cycle.

5.1 Probe Loading and Positioning

5.1.1 Loading

```
LOADTL/TNO, PROBE, OSETNO, TOS

G91 G28 G00 Z0.                                      Load position.
G91 G40 G49 H00                                      Reset offsets.
Ttno M06                                             Load probe.
G91 G43 Z0. Htos                                     Set probe length offset
M119                                                 Switch probe on.
G90                                                  Absolute mode.
```

5.1.2 Protected Positioning

```
FEDRAT/f, IPM
GOTO/x, y, z

G101 Xx Yy Zz Ff
```

- G101 is invoked only if the modifier *PROBE* has been specified in the previous *LOADTL* command. Otherwise a G01 (linear interpolation) is invoked.

5.2 Calibration Functions

5.2.1 Probe Center

```
CYCLE/CALIBR, CENTER, DIAMTR, d

G106 Dd
```

- The diameter d must be greater than 20 mm.

5.2.2 Probe Diameter

CYCLE/CALIBR, DIAMTR, d, WOSET, s

G105 Dd Ss

- The diameter d must be greater than 25 mm.

5.2.3 Probe Length

CYCLE/CALIBR, LENGTH, OSETNO, t

G107 Z(next) Tt

- T must be programmed.

5.3 Datuming Functions

5.3.1 Internal Corner

CYCLE/DATUM, ICORNR, WOSET, s, OVTRAV, q

G111 X(next) Y(next) Ss Qq

- S must be programmed.

5.3.2 External Corner

CYCLE/DATUM, ECORNR, WOSET, s, OVTRAV, q

G112 X(next) Y(next) Ss Qq

- S must be programmed.

5.4 Measuring Functions

5.4.1 Web

CYCLE/MEASUR, WEB, THICK, l, WOSET, s, OSETNO, t, ERRNO, m, ^
TLRNCE, h, RAPTO, r,FEDTO, iz, OVTRAV, q, PRTDIM, v

G110 Xl or Yl Ss Tt Mm Hh Rr Z(next+iz) Qq Vv

- Xl or Yl is determined by the axis whose position value has changed from the previous point to the next point.
- The cadcam program does not use 'FEDTO,iz' but rather supplies the gauging depth directly through Z of the next point.
- S and T may be used together.

5.4.2 Pocket

```
CYCLE/MEASUR, POCKET, THICK, l, WOSET, s, OSETNO, t, ^
          ERRNO, m, TLRNCE, h, OVTRAV, q, PRTDIM, v
```

```
G110 Xl or Yl Ss Tt Mm Hh Qq Vv
```

- Xl or Yl is determined by the axis whose position value has changed from the previous point to the next point.
- S and T may be used together.

5.4.3 Boss

```
CYCLE/MEASUR, BOSS, DIAMTR, d, WOSET, s, OSETNO, t, ERRNO, m, ^
          TLRNCE, h, RAPTO, r, FEDTO, iz, OVTRAV, q, PRTDIM, v, PRTPOS, w
```

```
G119 Dd Ss Tt Mm Hh Rr Z(next+iz) Qq Vv Ww
```

- The cadcam program does not use 'FEDTO,iz' but rather supplies the gauging depth through Z of the next point.
- S and T may be used together.
- T is currently not programmable due to a bug.

5.4.4 Bore

```
CYCLE/MEASUR, BORE, DIAMTR, d, WOSET, s, OSETNO, t, ^
          ERRNO, m, TLRNCE, h, OVTRAV, q, PRTDIM, v, PRTPOS, w
```

```
G119 Dd Ss Tt Mm Hh Qq Vv Ww
```

- S and T may be used together.
- T is currently not programmable due to a bug.

5.4.5 Z Surface

```
CYCLE/MEASUR, ZSURF, WOSET, s, OSETNO, t, ERRNO, m, ^
          TLRNCE, h, OVTRAV, q, PRTDIM, v
```

```
G118 Z(next) Ss Tt Mm Hh Qq Vv
```

- S and T may not be used together.

5.4.6 XY Surface

```
CYCLE/MEASUR, XYSURF, WOSET, s, OSETNO, t, ERRNO, m, TLRNCE, h, ^
          UPPTOL, u, RAPTO, r, FEDTO iz, OVTRAV, q, PRTDIM, v
```

```
G113 X(next) or Y(next) Ss Tt Mm Hh Uu Rr Z(next+iz) Qq Vv
```

- X(next) or Y(next) is determined by the axis whose position value has change from the previous point to the next point.
- R and 'FEDTO,iz' are not used by the cadcam program. Rather, the clearance and the gauging depth are supplied directly by the X Y Z of the previous (start) point.
- S and T may not be used together.

6 Probe Programming in Anvil-5000

6.1 Concepts

6.1.1 Interaction

The probe programming is done in the same environment as Anvil's standard functions. The user selects options from a tree of menus. He is prompted with messages for operations that are required on his part. He uses the mouse to indicate features on the model. He may set and change modals that control the execution of the program. He may edit a probe path created by the program, add to it or delete from it. The probe path created is a standard Anvil tool path and may later be manipulated, displayed, edited, combined with a composite tool path and used for NC output. The path is created continuously as the probe functions are selected.

Standard interactions with the mouse such as entity selection, O/C (operation complete) and REJECT are retained.

6.1.2 Program Phases

The user is proceeding through the following steps in the program (Refer also to fig. 3.3):

Startup: The Grapl program is started or restarted.

Modals Settings: The program's modals are set or reset, including feedrates, intermediate planes and offset and error registers.

Probe Cycle Start: The probe is moved to the clearance plane and switched on.

Function Selection: A probing function is selected from the main menu. The user is prompted to indicate an entity or entities on the feature to be gauged, to enter the location of the start and target points with respect to a previously indicated reference point, and to enter values for the cycle parameters.

Path Creation: The path is created automatically once all the selections have been completed. The path does not include a full graphical presentation of the probing cycle itself, but rather a symbolic motion from the start point directly to the target point. The positioning of the probe prior to the cycle itself and after it is fully presented.

Repeat Cycle or Terminate: The user may proceed with a selection of a new function. He may reset the modal values prior to that. Or, he may terminate the program and return to Anvil's menu system.

Display and Edit: The user may inspect and edit the probe path with Anvil's display and edit menu.

Program Restart: The program may be restarted to append additional cycles to a probe path previously created. Care should be taken to set the error registers properly.

NC Output: The path is now selected via Anvil's NC output menu to produce a Clprint output file, which is later post processed and sent to the machine for execution.

6.1.3 Program Modes

Execution Location:

The current version of the program may be executed from the Grapl menu only. It uses *keystroke files* extensively to enter and exit the *display and edit* menu where the probe path is created. This results in a fully automatic operation, but with a sluggish response and inflexibility.

The new Anvil's revison 1.1.8 supports execution of Grapl programs from within the machining menu. Thus, the probe program may be executed inside the machining menu with faster response and with the full flexibility provided by Anvil's NC package. The programming would be, though, less automatic, and a few changes will be required in the program to override the keystroke files.

Error Registers:

Currently the probe program assigns incremental numbers to the gauging error memory registers, starting from 21 up to 32. This limits the number of measuring cycles in a particular probe path to 12.

With the expected installation of an additional RS232 port to the machine tool, The gauging errors may be sent continuously back to the host computer, without storing them in the offset registers. This would require changes in the program to invoke printing commands.

6.1.4 Coordinate Systems

The probe program creates probe paths in *model space coordinates* only. This coordinate system is the one in which the model is always created in Anvil, and to which Anvil's data base corresponds. In Anvil's view No. 1 the X axis is horizontal to the right, the Y axis is vertical upward and the Z axis is normal to the screen outward. *Definition coordinate system (DCS)* may not be used (which is a disadvantage). The DCS is a coordinate system that may be defined by the user and attached to the model. DCS may be activated after the completion of the probe path for conveniency in NC output preparation.

6.2 Startup and Main Menu

Start a part in Anvil. From the main menu select *6. DATA BASE MANAGEMENT* and then *7. MODIFY DEFAULT DIRECTORIES*. Change the default directories of *2. PATTERN FILE DIRECTORY, 3. UTF FILE DIRECTORY* and *6. KEYSTROKE FILE DIRECTORY* to */usr/cell/cad/probe*. (A keystroke file may be written to shorten this procedure).

Blank all displayed tool paths prior to starting the program, to prevent the automatic path selection feature of the program from selecting the wrong tool path. Also, activate a DCS on the display to ensure that the probe's initial path, which is retrieved as a pattern, will be located properly on the model. This DCS is automatically deactivated after loading the initial path.

Return to main menu and select *5. SPECIAL FUNCTIONS* and then *2. GRAPL*. Select *2. RUN GRAPL PROGRAM* and enter the program name *P* (capital p). This will start the probe program.

The system displays the probe program's main menu *PROBE FUNCTION*:

1. MODALS
2. START PROBE CYCLE
3. CALIBRATE PROBE CENTER
4. CALIBRATE PROBE DIAMETER
5. CALIBRATE PROBE LENGTH
6. DATUM IN INTERNAL CORNER
7. DATUM IN EXTERNAL CORNER
8. MEASURE WEB
9. MEASURE POCKET
10. MEASURE BOSS
11. MEASURE BORE
12. MEASURE Z SURFACE
13. MEASURE XY SURFACE
14. SPATIAL LOCATION OF PART
15. SPECIAL FUNCTION
16. TERMINATE

Note: The user can return to anvil's main menu from anywhere in the program by pressin CTRL-F.

6.3 Program Steps

The user should proceed with the following steps, in the same order they appear:

Step 1	Modals Settings
Step 2	Probe Cycle Start
Step 3	Function Selection
Step 4	Indication of Features
Step 5	Direction Selection
Step 6	Start Point Location
Step 7	Setting Target Depth and Parameters
Step 8	Repeat Cycle / Terminate

6.3.1 Modals Settings

Select menu item *1. MODALS*. The system displays the message *ENTER PROBE PARAMETERS* and the data entry menu with the parameters' default values (Refer also to fig. 3.3):

1.	RAPID FEED	= 100.00	Rapid feedrate (FRA)
2.	ENTRY FEED	= 20.00	Entry feedrate (FEN)
3.	EXIT FEED	= 40.00	Exit feedrate (FEX)
4.	CLRNC DPTH	= 4.00	Clearance plane depth (CCZ)
5.	RTRCT DPTH	= 6.00	Retraction plane depth (CRZ)
6.	TOOL #	= 15.00	Probe tool number (TNO)
7.	OFFSET #	= 15.00	Probe length offset number (TOS)
8.	ERR ADDRES	= 21.00	First error address (REG)

The user may modify the values or proceed with O/C. The definitions of the parameters are explained in chapter 3 and fig 3.3. The modals may be modified before the probe cycle start and before each selection of a probing function from the main menu. Each time the program is started, the modals are reset to their default values.

The *feedrates* should be chosen such that rapid is the maximum workable speed of the machine, entry is a slow speed used when the probe plunges down to a start point and might bump into an obstacle and exit is a medium speed for retracting upwards from the part.

The *clearance plane* may be defined to suit the maximum height of a local group of features on the part and may be modified for probing in another area of the part.

The *tool number* and *offset number* should correspond to the setup on the machine.

The *first error address* modal denotes the *first* register assigned. The next registers will be incremented automatically for each gauging cycle that produces an error output. When the program is running, this modal shows the current register assigned to the error. A restart of the program will reset the value to the default.

6.3.2 Probe Cycle Start

Select menu item *2. START PROBE CYCLE*. The system automatically retrieves an initial probe path and locates it in (0,0,0). This path contains the probe tool definitions and a dummy move. The system then executes a keystroke file that deletes the dummy motion and moves the probe rapidly to a retraction plane in (0,0,retract depth), and then to a clearance plane in (0,0,clearance depth). The coordinates correspond to the DCS activated in the startup (par. 6.2).

If a DCS is not active, a keystroke file error message is shown. Proceed by pressing O/C twice, but be aware that the initial path may be located incorrectly (possibly even outside the screen). Finally the system deactivates the active DCS and returns to the model space coordinates in which the probe path is created.

6.3.3 Function Selection

Select a function - menu items 3 to 15. Menu item *15. SPECIAL FUNCTION* is reserved for future enhancements. The user may exit a function before completion by pressing REJECT while in any of the data entry/modify menus.

6.3.4 Indication of Features

The user is requested to indicate points and/or circles on the model with the mouse. The system displays a single message or two messages in a sequence. The messages are *INDICATE CIRCLE* and *INDICATE CIRCLE CENTER* for the circular features, *INDICATE A POINT ON THE SURFACE* for the surfaces, *INDICATE A POINT ON THE CORNER* for the corners, and *INDICATE A POINT ON FIRST SURFACE* and *INDICATE A POINT ON SECOND SURFACE* for the web and pocket. The points/circles may be selected with a large degree of flexibility. Refer to fig. 6.1 for instructions on features' selection and indication for each function.

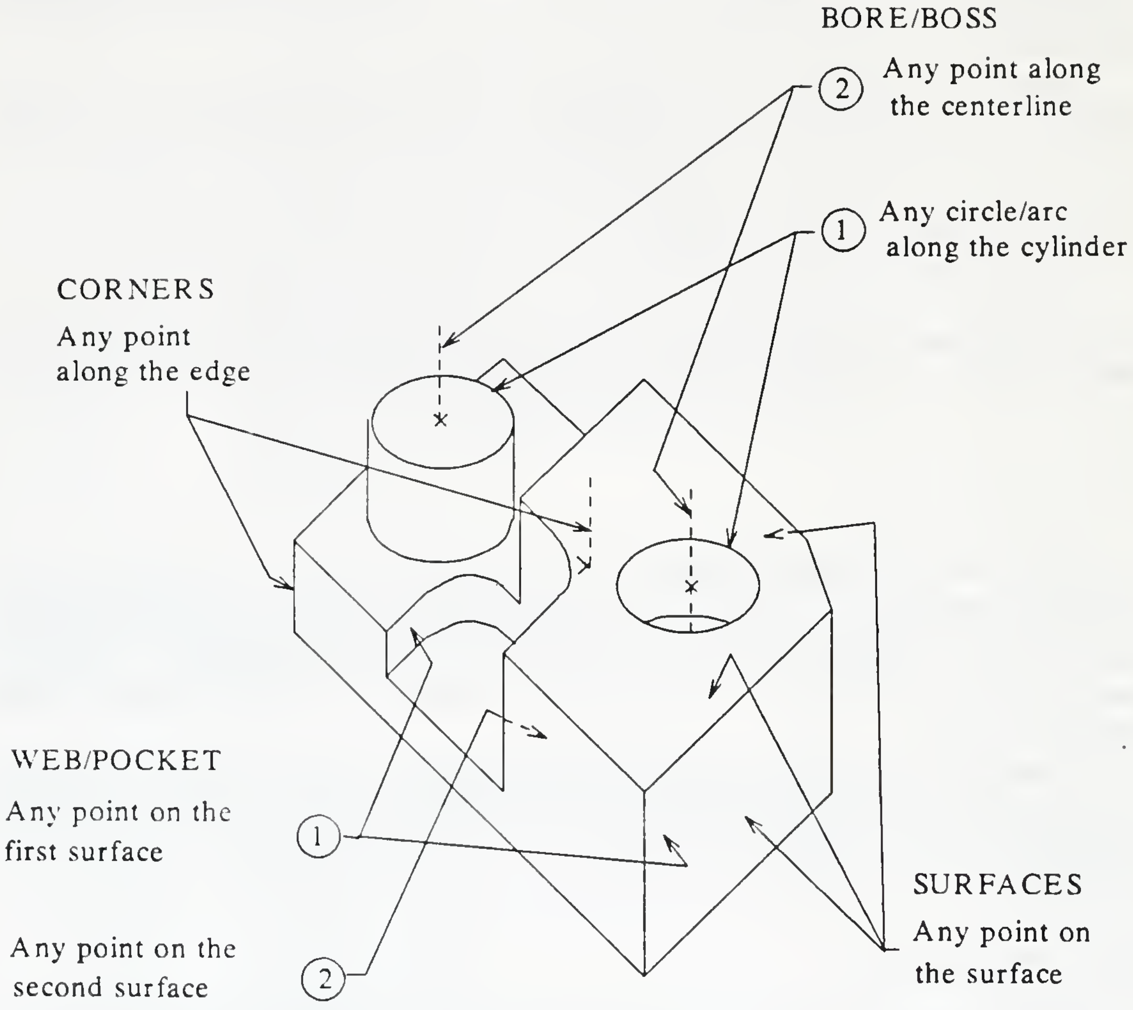
BORE/BOSS
② Any point along the centerline
① Any circle/arc along the cylinder
CORNERS
Any point along the edge
WEB/POCKET
Any point on the first surface ①
Any point on the second surface ②
SURFACES
Any point on the surface

Figure 6.1: Indication of Features on the Model

6.3.5 Direction Selection

This step applies to *Web, Pocket* and *XY Surface*. For a *XY Surface* this menu comes after the last interaction (after step 7).

The system displays the *MEASUREMENT DIRECTION* menu:

1. X AXIS
2. Y AXIS

Select the direction of measurement in either X or Y. Remember that the active coordinate system is model space. The direction axes must correspond to the machine tool main axes since the probe cycles are driven by the machine in these axes only. Vector motion (combined X and Y) is not available.

6.3.6 Start Point Location

The user is requested to enter the location of the *start point* as a signed distance from a reference indicated point of step 4.

For *Probe Center, Probe Diameter, Bore* and *Boss* the system displays the message *START POINT FROM CIRCLE CENTER* and the data entry menu:

1. DELZ START = 0.00

For *Probe Length, Internal Corner, External Corner, Z Surface* and *XY Surface* the system displays the message *START POINT FROM INDICATED POINT* and the data entry menu:

1. DELX START = 0.00
2. DELY START = 0.00
3. DELZ START = 0.00

For *Web* and *Pocket* the system displays the message *START POINT FROM FIRST INDICATED POINT* and either one of the following data entry menus (depending on the measurement direction resolved in step 5):

1. DELY START = 0.00
2. DELZ START = 0.00

Or:

1. DELX START = 0.00
2. DELZ START = 0.00

The user should enter the signed distance, in X and/or Y and/or Z as applicable, from the reference indicated point to the desired location of the start point. Remember that the active coordinate system is model space.

6.3.7 Setting Target Depth and Parameters

The user is requested to enter or modify the values of the target depth and the probe cycle parameters. The system displays the message *ENTER PROBE PARAMETERS* and a subset of the following entry/modify menu (depending on the function):

1.	DELZ TARGT	= 0	Incremental target depth (FEDTO)
2.	WORK OFSET	= 999	Work offset system (WOSET)
3.	TOOL OFSET	= 999	Tool offset register (OSETNO)
4.	ERR ADDRES	= 21-32	Error memory register (ERRNO)
5.	TOLERANCE	= 999	Tolerance of feature (TLRNCE)
6.	UPP TLRNCE	= 999	Upper tolerance (UPPTOL)
7.	RAD CLRNCE	= 999	Radial clearance from target (RAPTO)
8.	OVERTRAVEL	= 999	Overtravel beyond target (OVTRAV)
9.	PRINT DIM	= 999	Print options for dimensions (PRTDIM)
10.	PRINT POS	= 999	Print options for positions (PRTPOS)

Note: The default value 999 means that this option should be ignored by the post processor.

The *target depth* is specified as the signed distance in Z from the reference indicated point to the target.

If a *work offset* is specified the corresponding work system (not necessarily the current work) will be updated with the offset value of the current work *plus* the error measured. The values may be from 1 to 6, corresponding to G54 to G59 respectively.

If a *tool offset* is specified the corresponding tool register will be updated with the error measured. Normally the offset selected corresponds to the tool that has machined the gauged surface. The values may be from 1 to 20 (the controller also provides registers 21-32 but those are reserved for the probe errors).

The *error memory address* reflects the current assigned register. The value must be inside the default range, or vital information might be overwritten on the machine controller. The program starts by default at 21 and increments the value for each gauging cycle that produces an error result, up to the number 32. If the user proceeds with additional cycles the program displays the warning message *ADDRES EXCEEDS 32. CONTINUE ?*. If the user restarts a previously designed probe path the error address will reset to the default 21 and must be changed manually, or error registers will be overwritten.

If a *tolerance* is specified the controller will display a warning message in case the gauging error exceeds the value. If an *upper tolerance* is specified the machine will not update a tool offset, even if it was specified, in case the value is exceeded. This provision is intended for a broken tool and is available only on *XY Surface* gauging.

If a *radial clearance* is specified the value will override the probe macros' default (which is 5 mm). Radial clearance is the amount by which the probe travels beyond the edge of the target before plunging down. If an *overtravel* is specified the value will overrride the probe macros' default (which is 4 mm). Overtravel is the distance that the probe will travel beyond the expected location of the gauged surface.

The *print dimensions* and *print positions* options are used to send printed ouput to the host computer. Option 1 is data only. option 2 is data and header. These options are currently not available and should be left with the defaults. The system provides other printing utilities within the operating environment - refer to par. 3.3.4.

Not all the parameters appear in a particular probing function. The following table summarizes the applicabilities:

Parameter	*Center*	*Diamtr*	*Length*	*Corner*	*Web*	*Pocket*	*Boss*	*Bore*	*Z Surf*	*XY Surf*
DELZ TARGT					#		#			
WORK OFSET		+		#	+	+	+	+	+	+
TOOL OFSET			#		+	+	+	+	+	+
ERR ADDRES					+	+	+	+	+	+
TOLERANCE					+	+	+	+	+	+
UPP TLRNCE										+
RAD CLRNCE					+		+			
OVERTRAVEL				+	+	+	+	+	+	+
PRT DIM					+	+	+	+	+	+
PRT POS							+	+		

Notes:

Parameters denoted by '#' must be programmed. The rest, denoted by '+', may or may not be programmed according to the user's choice.

Work offset and tool offset parameters must not be used together in Z Suface and XY Suface. In other functions they may be mixed.

6.3.8 Repeat Cycle / Terminate

Upon completion of a probing cycle the user may select a new function from the main menu or terminate the program by selecting *16. TERNINATE*. The program may be restarted with an a existing probe path, but remember to set the error register and the modals to their correct values.

6.3.9 A Note on Spatial Location

Spatial location is used to provide points data for computing the part's misalignment and the needed transformation. When the user selects *14. SPATIAL LOCATION OF PART* the system displays the *PROBING PATTERN* menu:

1. 6 POINTS - 3D
2. 3 POINTS - 2D

The system will insert a note in the Clprint file which corresponds to the user's selection. This note is later used by a transformation utility to identify the type of spatial location intended.

The system then displays the message *USE FUNCTION 12 IN Z AND 13 IN XY*. The user should use functions *12. MEASURE Z SURFACE* and *13. MEASURE XY SURFACE* to probe 3 or 6 points on the part. Refer to fig. 6.2 and the explanation that follows for instructions as to the desired selection of points.

Instructions for The Selection of Points:

The following instructions provide rules of thumb for attaining higher accuracy of the part localization.

Select 3 points on the *primary surface*, 2 points on the *secondary surface* and 1 point on the *tritary surface*.

The surfaces must be planes, as normal to each other as possible, and as flat as possible. They should preferably be reference surfaces used for workholding the part for the incoming machining operations. Points may be selected on parallel planes instead of a single plane to achieve a greater span of points. In this case the parallel planes should be very accurate with respect to each other.

Select the points such that the dimensions d1, d2 and d3 on fig. 6.2 are as large as possible.

If only two machined surfaces are available for probing (which is the case if the part's top is yet to be machined) use the 3 point method, and make sure that the third surface is correctly attached to a fixture (usually the table plate).

If the misalignment is only translational, use the method of updating a work offset rather than the spatial location method.

Note:

3D part localization and data transformation requires the use of a 5-axis machine tool for machining the transformed data. If only a 3-axis machine is available use the 2D method or re-align the part according to the gauging results.

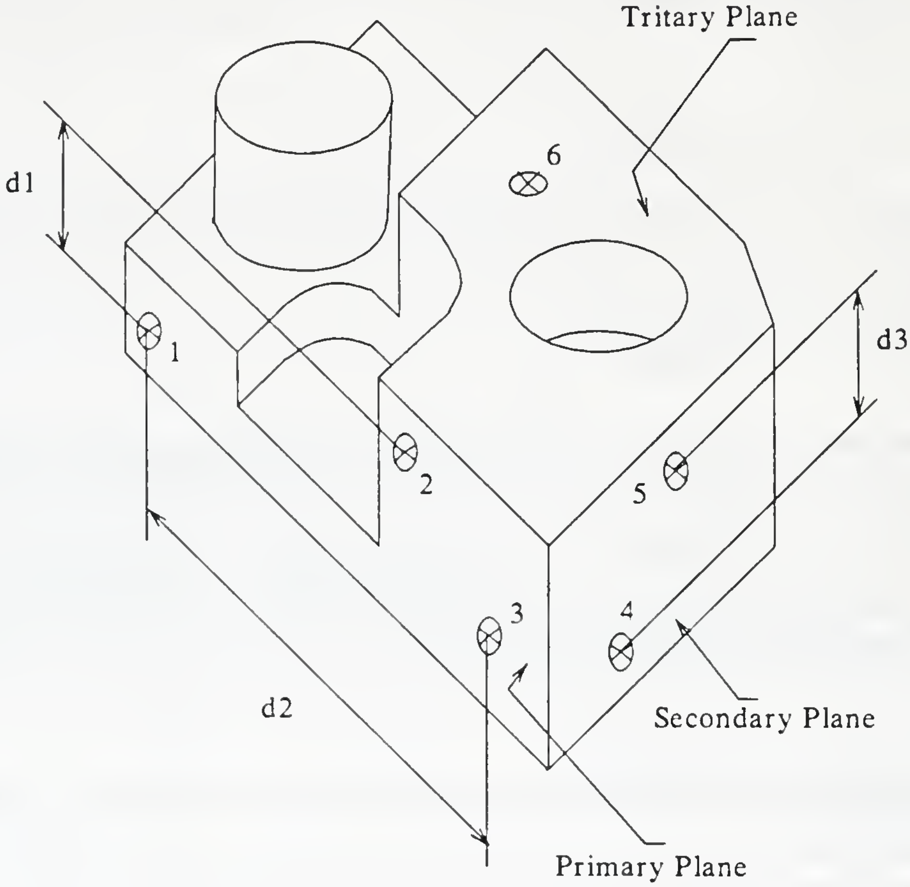

Figure 6.2: Selection of Points for Spatial Location of a Part

7 Application to Sample Cases

This chapter provides four examples of application. The examples are *Sample Part, Vise Calibration, Probe Calibration* and *Model Truck Spatial Location*. The examples include drawings and output files. A few changes were made to the original files for clarity.

7.1 Sample Part

This part is similar to the one used for the explanations throughout this text. Refer to fig. 7.1. The probe path includes the following steps: Loading and switching, datum in external corner for updating a work offset to compensate for translations, and measuring an XY surface, a pocket a boss and a bore.

The following related files are listed, in the same sequence they would appear in a typical programming and running process: A machining script file, which is a Unix batch file that executes the high level machining cell commands. A Clprint and a machine code output files. And, a printout of results from the machine.

Machining Script File:

The part localization is done here in translaton only, by updating work coordinate systems. Note that the localization of the part is done in two steps, firstly by searching and probing rough surfaces and secondly by probing fine surfaces. Note, also, that the work G55, which is a permanent coordinate system attached to the corner of the vise, is not affected. Rather, G56 is used as a temporary system that represets the original G55 *plus* the translational errors.

```
#! /bin/csh -x
#
# This file runs the following probe testing sequence:
# (1) Coarsely locate a part.
# (2) Finely locate a part.
# (3) Machine a part.
# (4) Measurement cycle.
#

rst                         # Reset machine tool modals
prst                        # Reset probe error registers

rpin                        # Right pallet in
code G55                    # Activate work coordinate G55
send coarse                 # Coarse location and updating G56
code M00                    # Temporary stop

code G56                    # Activate G56
send fine                   # Fine locating and updating G56
send machining              # Machine the part
send gauging                # Gauge the part
rpout                       # Right pallet out
```

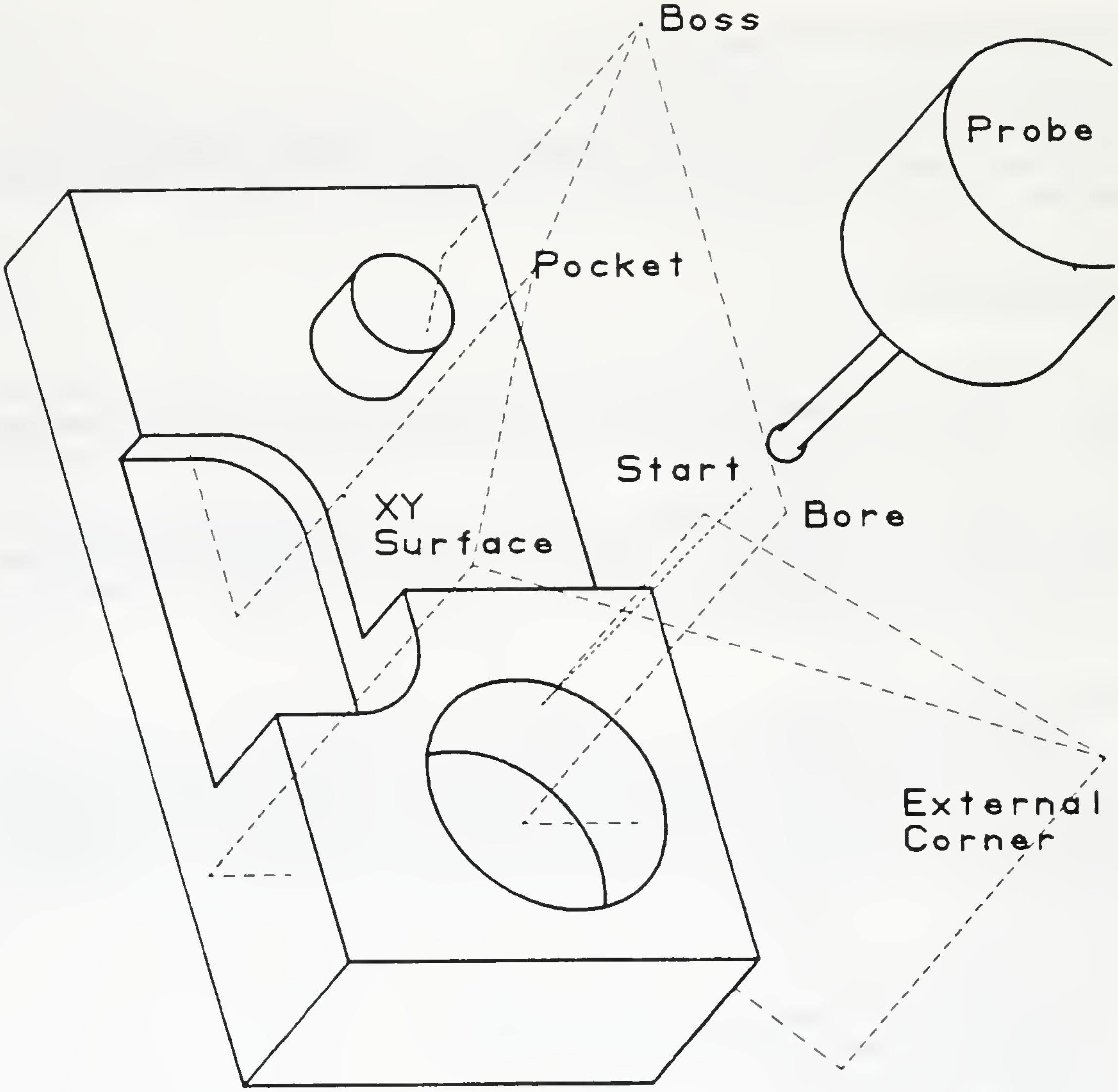

Figure 7.1: Probe Path on a Sample Part

Clprint Output File:

The following file contains the probe gauging cycle mentioned in step (4) of the machining script file above. Note the occasional updates of tool offsets (OSETNO), the specification of tolerance (TLRNCE), the use of the value 999 for parameters that are to be ignored and the use of the counting memory register (ERRNO).

```
INSERT/(PROBE CYCLE INITIATION)
LOADTL/15.0000,PROBE,OSETNO,15.0000
FEDRAT/100.0000
FROM/0.0000,0.0000,6.0000
GOTO/1.0000,1.0000,2.0000
INSERT/M01
INSERT/(END OF PROBE CYCLE INITIATION)
```

```
INSERT/(DATUM IN EXTERNAL CORNER)
FEDRAT/100.0000
GOTO/1.0000,1.0000,4.0000
GOTO/3.0000,-0.5000,4.0000
FEDRAT/20.0000
GOTO/3.0000,-0.5000,0.7592
CYCLE/DATUM,ECORNR,WOSET,3.0000,OVTRAV,0.5000
GOTO/2.5000,0.0000,0.7592
GOTO/3.0000,-0.5000,0.7592
FEDRAT/40.0000
GOTO/3.0000,-0.5000,4.0000
INSERT/M01
INSERT/(END OF DATUM IN EXTERNAL CORNER)
INSERT/(MEASURE XY SURFACE)
FEDRAT/100.0000
GOTO/3.0000,-0.5000,4.0000
GOTO/-0.5000,0.7000,4.0000
FEDRAT/20.0000
GOTO/-0.5000,0.7000,0.7592
CYCLE/MEASUR,XYSURF,WOSET,999.0000,OSETNO,7.0000,ERRNO,21.0000,^
CYCLE/TLRNCE,999.0000,UPPTOL,999.0000,OVTRAV,0.3000,PRTDIM,1.0000
GOTO/-0.0000,0.7000,0.7592
GOTO/-0.5000,0.7000,0.7592
FEDRAT/40.0000
GOTO/-0.5000,0.7000,4.0000
INSERT/M01
INSERT/(END OF MEASURE XY SURFACE)
INSERT/(MEASURE POCKET)
FEDRAT/100.0000
GOTO/-0.5000,0.7000,4.0000
GOTO/0.4000,2.5000,4.0000
FEDRAT/20.0000
GOTO/0.4000,2.5000,0.3592
CYCLE/MEASUR,POCKET,THICK,2.0000,WOSET,999.0000,OSETNO,999.0000,^
CYCLE/ERRNO,22.0000,TLRNCE,0.0050,OVTRAV,999.0000,PRTDIM,2.0000
GOTO/0.4000,3.5000,0.3592
GOTO/0.4000,2.5000,0.3592
FEDRAT/40.0000
GOTO/0.4000,2.5000,4.0000
INSERT/M01
INSERT/(END OF MEASURE POCKET)
INSERT/(MEASURE BOSS)
FEDRAT/100.0000
GOTO/0.4000,2.5000,4.0000
GOTO/1.5000,4.0000,4.0000
FEDRAT/20.0000
GOTO/1.5000,4.0000,1.5592
CYCLE/MEASUR,BOSS,DIAMTR,0.6000,WOSET,999.0000,OSETNO,9.0000,^
CYCLE/ERRNO,23.0000,TLRNCE,0.0100,RAPTO,0.3000,OVTRAV,999.0000,^
CYCLE/PRTDIM,999.0000,PRTPOS,1.0000
GOTO/1.8000,4.0000,0.7592
GOTO/1.5000,4.0000,1.5592
FEDRAT/40.0000
```

```
GOTO/1.5000,4.0000,4.0000
INSERT/M01
INSERT/(END OF MEASURE BOSS)
INSERT/(MEASURE BORE)
FEDRAT/100.0000
GOTO/1.5000,4.0000,4.0000
GOTO/1.5000,1.0000,4.0000
FEDRAT/20.0000
GOTO/1.5000,1.0000,0.7592
CYCLE/MEASUR,BORE,DIAMTR,1.4000,WOSET,999.0000,OSETNO,5.0000,^
CYCLE/ERRNO,24.0000,TLRNCE,0.0100,OVTRAV,0.3000,PRTDIM,999.0000,^
CYCLE/PRTPOS,999.0000
GOTO/2.2000,1.0000,0.7592
GOTO/1.5000,1.0000,0.7592
FEDRAT/40.0000
GOTO/1.5000,1.0000,4.0000
INSERT/M01
INSERT/(END OF MEASURE BORE)
COOLNT/OFF
SPINDL/OFF
REWIND/1.0000
FINI
```

Machine Code Output File:

This file is the post processed outcome of the Clprint file above. Note that the parameters with the 999 value were ignored.

```
O1
N5G90
(PROBE CYCLE INITIATION)
N10G91G28G00Z0.
N15G91G40G49H00
N20T15M06
N25G91G43Z0.H15
N30M119
N35G90
N40G101Z6.F100.
N45G101X0.Y0.
N50G101X1.Y1.Z2.
M01
(END OF PROBE CYCLE INITIATION)
(DATUM IN EXTERNAL CORNER)
N55G101Z4.F100.
N60G101X3.Y-0.5
N65G101Z0.7592F20.
N70G112X2.5Y0.S3Q0.5
N75G101X3.Y-0.5
N80G101Z4.F40.
M01
(END OF DATUM IN EXTERNAL CORNER)
(MEASURE XY SURFACE)
```

```
N85G101X-0.5Y0.7F100.
N90G101Z0.7592F20.
N95G113X0.T7V1M21Q0.3
N100G101X-0.5
N105G101Z4.F40.
M01
(END OF MEASURE XY SURFACE)
(MEASURE POCKET)
N110G101X0.4Y2.5F100.
N115G101Z0.3592F20.
N120G110Y2.M22V2H0.005
N125G101Y2.5
N130G101Z4.F40.
M01
(END OF MEASURE POCKET)
(MEASURE BOSS)
N135G101X1.5Y4.F100.
N140G101Z1.5592F20.
N145G119D0.6M23T9H0.01R0.3Z0.7592W1
N150G101X1.5Z1.5592
N155G101Z4.F40.
M01
(END OF MEASURE BOSS)
(MEASURE BORE)
N160G101Y1.F100.
N165G101Z0.7592F20.
N170G119D1.4Q0.3M24T5H0.01
N175G101X1.5
N180G101Z4.F40.
M01
(END OF MEASURE BORE)
N185M119
N190(=> Tool slot 16 should be EMPTY <=)
N195G91G28Z0.T16M06
```

Probing Results Printout:

Note that the printout contains all the offset registers, and not only those used or updated by the probe. The probing results for this part are contained in tool offsets 21 to 24. Note also the slight difference between the location of G55 and G56 which accounts for the translational error of the part.

```
 TOOL OFFSETS

NO.        DATA
 1       - 3.0060
 2       - 5.8607
 3       - 1.5557
 4          .0000
 5       - 2.5689
 6       - 2.0000
 7          .0000
```

```
  8          .0000
  9        - .7100
 10          .0000
 11          .0000
 12       - 2.3690
 13          .0000
 14       - 4.3289
 15        - .0007
 16          .0000
 17          .0000
 18          .0000
 19          .0000
 20          .0000
 21          .0153
 22          .0498
 23          .0001
 24        - .0025
 25          .0000
 26          .0000
 27          .0000
 28          .0000
 29          .0000
 30          .0000
 31          .0000
 32          .0000


WORK ZERO OFFSETS

  N0. 0  COMMON
X         .0000
Y         .0000
Z         .0000

  NO. 1  G 54
X       -15.8200
Y       -12.8400
Z       -10.9200

  NO. 2  G 55
X       -12.7196
Y       -10.1220
Z       - 7.5165

  NO. 3  G 56
X       -12.5293
Y       - 9.7083
Z       - 7.6031

  NO. 4  G 57
X       -12.5317
Y       - 9.7062
Z         .0000
```

NO. 5	G 58
X	-12.7196
Y	-10.1220
Z	- 5.8200

NO. 6	G 59
X	-12.7196
Y	-10.1220
Z	- 6.5156

7.2 Vise Calibration

The fixed face of the vise serves as a reference surface for the clamped workpiece. Typically a machine work coordinate will be attached to the vise and will correspond to the coordinate system in which the machining data files were created on the cadcam. Therefore a regular calibration of the location of the vise is important.

The calibration is done by using the probing functions *Z Suface (G118)* and *External Corner (G112)* to gauge the corner of the vise and to update the current work offset attached to it. The machine code file for that operation follows. This procedure is invoked by the cell command *prv*.

Machine Code File:

Note the use of machine macro variables denoted by # to extract the number of the current work from the controller.

```
O1
(PROBE VISE, CALIBRATE CURRENT WORK COORDINATE)
G91G28G00Z0
G91G40G49H00
T15M6
M119
G91G43H15Z0
G90
G101X-.2Y.2Z2.F100.
G101Z.2F20.
#1 = #4014 - 53(CURRENT WORK COORDINATE)
G118Z0S#1
G101X.2Y-.2
G101Z-.2
G112X0Y0S#1
G101Z2.F40.
H00
M119
G91G28Z0T16M6
```

7.3 Probe Calibration

Regular calibration of the probe is essential for an accurate and trouble free operation. A complete calibration procedure includes the setting of the stylus center offset, the triggering envelope and the length offset. A bored hole, a ring gauge (or the same hole) and a Z surface are used as reference features. The following script file describes the procedure adopted at NYU. This procedure is invoked by the cell command *pclb*.

Machining Script File:

The calibration procedure includes the following steps: Setup of tools, selection of the active pallet, manual registration of the probe (for measuring the actual length of the probe), boring a hole and gauging.

```
#
# Calibration of the Renishaw MP9 touch probe on the NYU machining cell.
# The calibration cycle includes probe center, probe diameter and
# probe length.
#
set noglob

#  Setup and instructions
#
echo 'CALIBRATION OF PROBE CENTER (G106), DIAMETER (G105)'
echo 'AND LENGTH (G107)'
echo 'Setup and Instructions:'
echo '  1. Right (left) vise with G55 (G54) attached to its fixed left'
echo '     outward corner.'
echo '  2. Tool No. 3 is a 1" center cutting end mill, with a proper offset.'
echo '  3. A 2" wide by 2" long aluminum scrap piece is mounted on the vise,'
echo '     flush with the top and adjacent to the G55 (G54) origin.'
echo '  4. The probe offset register has a value less than 0.1" .'
echo '  5. After boring the 1" hole and before proceeding with the probing'
echo '     the machine will pause. Clean thoroughly the vise and bore, '
echo '     and press Cycle Start to continue'
echo '  6. Follow additional instructions on the go'
echo ' '

echo -n "Continue with calibration process ? (type 'cont' to continue): "
        set ans = ($<)
        if ($ans == cont) then
                echo ' '
                echo 'PROBE CALIBRATION CYCLE'
                echo ' '
        else
                exit 1
        endif

rst                                     # Reset machine tool modals

echo -n 'Which pallet ? (l/r): '
```

```
    set pallet = ($<)
     if ($pallet = = r) then
            rpin                    # Right pallet in
     else
            lpin                    # Left pallet in
     endif

#   Manual registering of the probe
#
code G91 G28 Z0 T15 M6          # Load the probe tool
code G00 G90 X-.2 Y.2 Z1.       # Position the probe near the vise
code M119                       # Switch on the probe

echo ' '
echo 'Manual Registration of Probe:'
echo '   1. Switch mode selector to manual operation.'
echo '   2. Move probe manually down in Z untill you touch (a beep will'
echo '      sound). Use fine motion (HX1) close to touching.'
echo '   3. Set the Z value of G55 (G54) to the current (touch) machine Z value.'
echo '   4. Retract the probe away from the vise.'
echo '   5. Switch back to tape mode'.
echo '   6. Press cycle start.'
echo ' '

#   Boring calibration hole and executing calibration cycle
#
send bore_hole                  # Bore a calibration hole
send probe_calibration          # Gauge with calibration functions

if ($pallet = = r) then
        rpout                   # Right pallet out
else
        lpout                   # Left pallet out
endif
```

7.4 Model Truck Spatial Location

Spatial location is demonstarted with the model truck produced for vision experiments in NYU. Refer to fig. 7.2 for the selection of the points. A Clprint file including the gauging of 6 points on the model follows.

Clprint Output File:

Note the title *spatial location - 6 points* at the beginning of the file, which denotes that this is a spatial location function. Note also the use of the overtravel parameter (OVTRAV) with a value of 0.5" to enable the search of the part within a reasonable misalignment envelope.

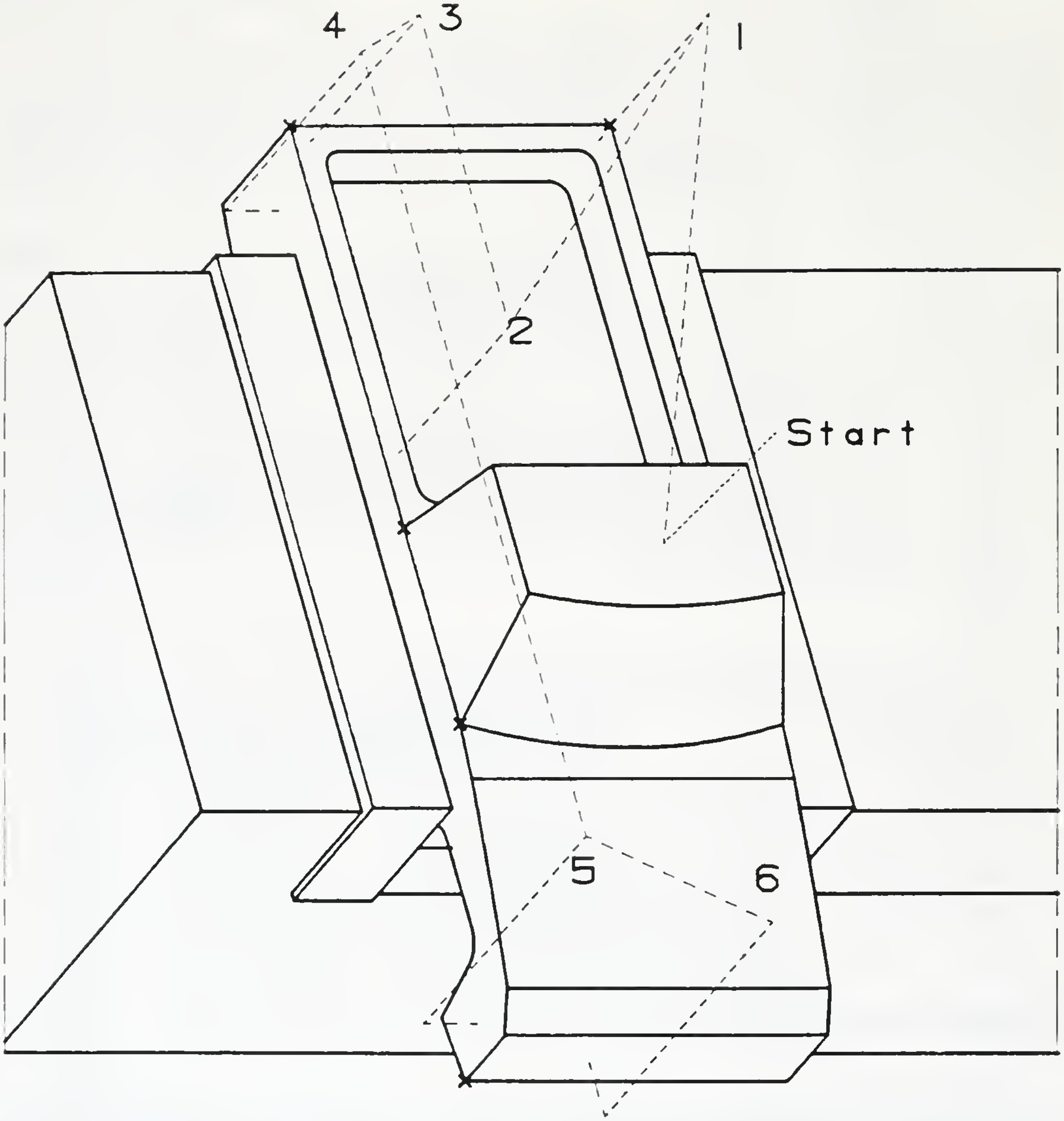

Figure 7.2: Spatial Location of a Model Truck

```
INSERT/(PROBE CYCLE INITIATION)
LOADTL/15.0000,PROBE,OSETNO,15.0000
FEDRAT/100.0000
FROM/0.0000,0.0000,6.0000
GOTO/1.0000,1.0000,2.5000
INSERT/M01
INSERT/(END OF PROBE CYCLE INITIATION)
INSERT/(***************************)
```

```
INSERT/(SPATIAL LOCATION - 6 POINTS)
INSERT/(***************************)
INSERT/(MEASURE Z SURFACE)
FEDRAT/100.0000
GOTO/1.0000,1.0000,2.5000
GOTO/2.8421,5.9287,2.5000
FEDRAT/20.0000
GOTO/2.8421,5.9287,0.9431
CYCLE/MEASUR,ZSURF,WOSET,999.0000,OSETNO,999.0000,ERRNO,21.0000,^
CYCLE/TLRNCE,999.0000,OVTRAV,0.5000,PRTDIM,999.0000
GOTO/2.8421,5.9287,0.4431
GOTO/2.8421,5.9287,0.9431
FEDRAT/40.0000
GOTO/2.8421,5.9287,2.5000
INSERT/M01
INSERT/(END OF MEASURE Z SURFACE)
INSERT/(MEASURE Z SURFACE)
FEDRAT/100.0000
GOTO/2.8421,5.9287,2.5000
GOTO/0.1500,3.0307,2.5000
FEDRAT/20.0000
GOTO/0.1500,3.0307,0.9431
CYCLE/MEASUR,ZSURF,WOSET,999.0000,OSETNO,999.0000,ERRNO,22.0000,^
CYCLE/TLRNCE,999.0000,OVTRAV,0.5000,PRTDIM,999.0000
GOTO/0.1500,3.0307,0.4431
GOTO/0.1500,3.0307,0.9431
FEDRAT/40.0000
GOTO/0.1500,3.0307,2.5000
INSERT/M01
INSERT/(END OF MEASURE Z SURFACE)
INSERT/(MEASURE Z SURFACE)
FEDRAT/100.0000
GOTO/0.1500,3.0307,2.5000
GOTO/0.1500,5.9287,2.5000
FEDRAT/20.0000
GOTO/0.1500,5.9287,0.9431
CYCLE/MEASUR,ZSURF,WOSET,999.0000,OSETNO,999.0000,ERRNO,23.0000,^
CYCLE/TLRNCE,999.0000,OVTRAV,0.5000,PRTDIM,999.0000
GOTO/0.1500,5.9287,0.4431
GOTO/0.1500,5.9287,0.9431
FEDRAT/40.0000
GOTO/0.1500,5.9287,2.5000
INSERT/M01
INSERT/(END OF MEASURE Z SURFACE)
INSERT/(MEASURE XY SURFACE)
FEDRAT/100.0000
GOTO/0.1500,5.9287,2.5000
GOTO/-0.5000,5.5787,2.5000
FEDRAT/20.0000
GOTO/-0.5000,5.5787,-0.0569
CYCLE/MEASUR,XYSURF,WOSET,999.0000,OSETNO,999.0000,ERRNO,24.0000,^
CYCLE/TLRNCE,999.0000,UPPTOL,999.0000,OVTRAV,0.5000,PRTDIM,999.0000
GOTO/0.0000,5.5787,-0.0569
```

```
GOTO/-0.5000,5.5787,-0.0569
FEDRAT/40.0000
GOTO/-0.5000,5.5787,2.5000
INSERT/M01
INSERT/(END OF MEASURE XY SURFACE)
INSERT/(MEASURE XY SURFACE)
FEDRAT/100.0000
GOTO/-0.5000,5.5787,2.5000
GOTO/-0.5000,-1.7000,2.5000
FEDRAT/20.0000
GOTO/-0.5000,-1.7000,-0.5113
CYCLE/MEASUR,XYSURF,WOSET,999.0000,OSETNO,999.0000,ERRNO,25.0000,^
CYCLE/TLRNCE,999.0000,UPPTOL,999.0000,OVTRAV,0.5000,PRTDIM,999.0000
GOTO/0.0000,-1.7000,-0.5113
GOTO/-0.5000,-1.7000,-0.5113
FEDRAT/40.0000
GOTO/-0.5000,-1.7000,2.5000
INSERT/M01
INSERT/(END OF MEASURE XY SURFACE)
INSERT/(MEASURE XY SURFACE)
FEDRAT/100.0000
GOTO/-0.5000,-1.7000,2.5000
GOTO/1.0000,-2.5000,2.5000
FEDRAT/20.0000
GOTO/1.0000,-2.5000,-0.6113
CYCLE/MEASUR,XYSURF,WOSET,999.0000,OSETNO,999.0000,ERRNO,26.0000,^
CYCLE/TLRNCE,999.0000,UPPTOL,999.0000,OVTRAV,0.5000,PRTDIM,999.0000
GOTO/1.0000,-2.0000,-0.6113
GOTO/1.0000,-2.5000,-0.6113
FEDRAT/40.0000
GOTO/1.0000,-2.5000,2.5000
INSERT/M01
INSERT/(END OF MEASURE XY SURFACE)
COOLNT/OFF
SPINDL/OFF
REWIND/1.0000
FINI
```

8 Programs Structure and Installation

8.1 Overview

Programming in Anvil's environment is different from conventional programming. For this reason the following chapter and the related appendices are somewhat detailed.

The main building blocks of the program are: Grapl programs, Post Processor NC Macros, Keystroke files and Pattern files. They are all explained in details in Anvil's manuals [9]. The Grapl programs run the Anvil like environment that enables the use of menus, indication of features and creation of geometries. The keystroke files are used to enter Anvil's *Display and Edit* menu for the creation of the probe path. The post processor NC macros create the probe path itself, using variables' values specified in the Grapl program. The pattern file is used to load predefined Anvil graphic entities into the current part.

This chapter contains the list of the program files, a description of the program execution flow and instructions for the installation of future updates. Refer also to appendices A to C for excerpts from the programs and additional information.

8.2 Files and Extensions

All the program files are contained in the */usr/cell/cad/probe* directory on Cadman (the host computer). The various file extensions are:

.dat	Grapl programs' source and post processor macros in Ascii format.
.gsr	Grapl programs' source in Anvil's format (UTF files).
.gpl	Grapl executables in Anvil's format.
.ksf	Keystroke files in Ascii format.
.ppm	Post processor macros in Anvil's format (UTF files).
.pat	Pattern files.

The list of all files follows. The first group contains the Grapl programs, the second contains the startup functions and the third contains the gauging functions.

P.dat	P.gpl	P.gsr
PP.dat		PP.gsr

	dcsoff.ksf		
goprobe.dat	goprobe.ksf	goprobe.ppm	goprobe.pat

3points.dat	3points.ksf	3points.ppm
6points.dat	6points.ksf	6points.ppm
bore.dat	bore.ksf	bore.ppm
boss.dat	boss.ksf	boss.ppm
center.dat	center.ksf	center.ppm
diamtr.dat	diamtr.ksf	diamtr.ppm
ecornr.dat	ecornr.ksf	ecornr.ppm
icornr.dat	icornr.ksf	icornr.ppm
length.dat	length.ksf	length.ppm
pocket.dat	pocket.ksf	pocket.ppm
web.dat	web.ksf	web.ppm

xysurf.dat	xysurf.ksf	xysurf.ppm
zsurf.dat	zsurf.ksf	zsurf.ppm

Notes:

- Grapl program *PP* is linked to the program *P*. Therefore there is only a single compiled executable *P.gpl*. The reason for the use of two Grapl programs is Anvil's file size limitation.

- The keystroke file *dcsoff.ksf* is used to turn off the active DCS and return to the model space coordinates after loading the initial probe path.

- The pattern file *goprobe.pat* contains an initial probe path with all the probe tool definitions. This initial path is then updated by *goprobe.ksf*.

- All the post processor macro files (.ppm) are called from within the corresponding keystroke files (.ksf).

8.3 Program Flow

Abbreviations used hereafter:

- KSF Key Stroke File
- PPM Post Processor NC Macro
- RTL Run Time Library
- DCS Definition Coordinate System

```
Grapl Program P
  Set modals' deffaults
  Set parameters defaults
  Save defaults to RTL
  Display main menu
  Change modals and save to RTL

  Start probe cycle
        Retrieve pattern goprobe.pat
        Run KSF goprobe.ksf
                                    KSF goprobe.ksf
                                    Goto display and edit
                                    Insert PPM goprobe.ppm
                                                          PPM goprobe.ppm
                                                          Read variables from RTL
                                                          Move to retraction plane
                                                          move to clearance plane
                                                          Return
                                    Return
        Turn off the active DCS

  Select gauging function
        Indicate gauged features
        Select gauging direction
        Set start point
        Set target depth and probe parameters
        Save values to RTL
```

```
    Run KSF function.ksf
                        KSF function.ksf
                        Goto display and edit
                        Insert PPM function.ppm
                                            PPM function.ppm
                                            Read variables from RTL
                                            Move to start point
                                            Invoke function cycle
                                            Return to clearance plane
                                            Return
                        Return
    Return

  Reset modals if desired
  Select additional probing function
  :
  :
  :
  Link Grapl program PP

Grapl Program PP
  Refer to Grapl program P
  Select additional probing function
  :
  :
  :
  Terminate
```

8.4 Updates and Recompilation

Updates for the Grapl programs and the post processor NC macros may be inserted in the *.dat Ascii files. The Grapl program is then read into Anvil's *.gsr format (using menu item 5-2-4) and compiled when the program is run (using menu item 5-2-2). The program *PP* is compiled automatically with program *P*, and a single executable object code is created with the name *P.gpl*. Post processor macros are read into Anvil's *.ppm format (using menu item 17-15-2).

Keystroke files may be changed by text editing of the files or by rerunning them.

9 Deficiencies and Future Enhancements

Following is a list of the system deficiencies and possible future enhancements. The list is sorted to probe and machine related problems and to cadcam related problems.

9.1 Probe and Machine

The probe may gauge along the machine's main axes only. E.g., it is not possible to gauge a slant plane in a direction normal to it. This feature may be useful for gauging a largely misaligned workpiece. The solution entails writing special machine macros. Alternatively, it may be ordered from Renishaw.

The probe macros currently have a few bugs that have not been resolved by the manufacturer: G118 (measure a Z surface) ignores an overtravel parameter (Qq) and defaults to its own value. G119 (measure bore/boss) does not accept a tool offset parameter (Tt).

The machine tool cannot send output when it is reading a program input. Therefore the current program stores the probing results in tool registers for later use. The number of available registers in our case is only 12, which is too small for special applications such as digitization of sculptured surfaces. The solution entails installing an additional RS232 port on the machine tool with proper settings, and the addition of printing post processor NC macros to the program. Refer to the description of the digitizing system from Suburban Machinery [15].

9.2 Cadcam

The system currently works in model space coordinates. The use of a DCS is not suitable. The solution entails a direct access to Anvil's database via the *Interface Kit* (which we have not purchased).

The system uses keystroke files extensively with the drawbacks of sluggish response and sensitivity to new Anvil versions (the KSF depends on the menus tree). An alternative is to operate the Grapl program from within the machining menu and calling the post processor NC macros manually. This method provides higher flexibility (though a less automatic operation). The option will become available in Anvil Release 1/Revision 1.8 and entails changes in the Grapl programs to bypass the KSF's.

The system is able to localize parts that have 3 normal planes oriented in the machine main directions. A future solution may enable the localization of an arbitrarily shaped part. The theoretical aspects of this problem are discussed in a separate paper [16].

The industry is starting to introduce sophisticated dimensional inspection systems based on touch probes. Such a system is the Softgauge (TM) from Valisys Corporation [17] , which offers a wide variety of probe applications using cadcam systems. A future purchase of such a system may be considered.

Acknowledgments

I would like to thank:

Mr. Joe Sommers and Mr. Dale Hubbard from Synermation Corporation for their professional guidance in the specification of the post processor probe commands.

Mr. Leo Somerville from Renishaw Corporation for his knowledgeable explanations on the probe operation and macros.

Mr. Fred Hansen for his hardware support in the machining cell.

Mr. John Deragon for his hardware support and for writing software utilities for the probe outputs.

Mr. Elias Pavlakos for writing the coordinate transformation software.

And finally, Professor Paul K. Wright for his support and guidance along the way of building and running the machining cell.

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Appendix A: Grapl Programs

This appendix contains excerpts from Grapl programs *P.dat* and *PP.dat*. Notice the structure of blocks and the absence of sub-routines and functions which are not supported by Grapl. Note also the calls for patterns and keystroke files, the use of function and data entry menus, and the saving of variables to Anvil's run time library.

Program P.dat:

```
$$      PROGRAM NAME: P.dat
$$      ****************************
$$      PURPOSE: CREATES PROBING PROGRAMS
$$      INPUT: VALUES FOR PROBE PARAMETERS
$$      OUTPUT: VARIABLES' VALUES TO BE INCLUDED IN THE PROBE
$$            MACROS CALLED FROM WITHIN THE PROGRAM, USING
$$            KEYSTRIKE FILES AND THE DISPLAY AND EDIT MODE.
$$      WRITTEN BY: ISRAEL GREENFELD, MAY 88
$$
$$
      SIZE RDAT(20), IDAT(20)
      SIZE PNT(20), LN(20), CRCL(20)
$$
$$      SET DEFFAULT PARAMETERS' VALUES
$$      ********************************************
$$      THE VALUE OF 999 CAUSES THE POST PROCESSOR TO IGNOR AN
$$      ADJACENT PARAMETER
$$
3      CONT/
$$      MODALS VALUES:
$$
      FRA = 100                          $$ RAPID FEEDRATE
      FEN = 20                           $$ ENTRY FEEDRATE
      FEX = 40                           $$ EXIT FEEDRATE
      CCZ = 4                            $$ CLEARANCE PLANE
      CRZ = 6                            $$ RETRACT PLANE
      TNO = 15                           $$ PROBE TOOL NUMBER
      TOS = 15                           $$ PROBE OFFSET REGISTER
      REG = 21                           $$ FIRST MEMORY REGISTER
$$
      SAVE FRA, FEN, FEX, CCZ, CRZ, TNO, TOS, REG
$$
      m = REG             $$ (ERRNO)   ERROR MEMORY ADDRESS
$$
5      CONT/
$$      PROBE PARAMETERS VALUES AND START POSITION:
$$
      iz= 0               $$ (FEDTO)   INCREMENTAL DEPTH OF TARGET
      s = 999             $$ (WOSET)   WORK OFFSET SYSTEM
      t = 999             $$ (OSETNO)  TOOL OFFSET REGISTER NUMBER
      h = 999             $$ (TLRNCE)  TOLERANCE OF FEATURE TO BE GAUGED
      u = 999             $$ (UPPTOL)  UPPER TOLERANCE ( G113 ONLY)
      r = 999                 $$ (RAPTO)   RADIAL CLEARANCE FROM TARGET
      q = 999                 $$ (OVTRAV)  PROBE OVERTRAVEL
      v = 999                 $$ (PRTDIM)  PRINT OPTIONS FOR DIMENSIONS
      w = 999                 $$ (PRTPOS)  PRINT OPTIONS FOR POSITION (G119)
$$
      l = 0                   $$ (THICK)   WEB/POCKET THICKNESS
      d = 0                   $$ (DIAMTR)  DIAMETER OF MEASURED FEATURE
$$
      DELX = 0                $$ INCREMENTAL X OF MEASURE START POINT
      DELY = 0                $$ INCREMENTAL Y OF MEASURE START POINT
      DELZ = 0                $$ INCREMENTAL Z (DEPTH) OF MEASURE START POINT
$$
      IF (m.GT.32) GOTO 6                   $$ CHECK FOR ADDRESS OVERFLOW
      GOTO 7
6        QUERY/'ADDRESS EXCEEDS 32. CONTINUE ?', RESP, STAT
           IF (RESP.EQ.2) GOTO 160              $$ NO
           m = 32
7      CONT/
$$
      SAVE iz, s, t, m, h, u, r, q, v, w, l, d
      SAVE DELX, DELY, DELZ
$$
$$      MAIN MENU
$$      **************
$$
      MENU/'PROBE FUNCTION', $
         'MODALS•START PROBE CYCLE•CALIBRATE PROBE CENTER•' $
         'CALIBRATE PROBE DIAMETER•CALIBRATE PROBE LENGTH•' $
         'DATUM IN INTERNAL CORNER•DATUM IN EXTERNAL CORNER•' $
         'MEASURE WEB•MEASURE POCKET•MEASURE BOSS•' $
         'MEASURE BORE•MEASURE Z SURFACE•MEASURE XY SURFACE•' $
         'SPATIAL LOCATION OF PART•SPECIAL FUNCTION•' $
         'TERMINATE•', ISW, STAT
$$
   GOTO (10,20,30,40,50,60,70,80,90,100,110,120,130,140,150,160),ISW
$$
10     CONT/
$$      MODALS
$$      *********
$$
      RDAT(1) = FRA                         $$ RAPID FEEDRATE
      RDAT(2) = FEN                         $$ ENTRY FEEDRATE
      RDAT(3) = FEX                         $$ EXIT FEEDRATE
      RDAT(4) = CCZ                         $$ CLEARANCE PLANE
      RDAT(5) = CRZ                         $$ RETRACT PLANE
      IDAT(1) = TNO                         $$ PROBE TOOL NUMBER
      IDAT(2) = TOS                         $$ PROBE OFFSET REGISTER
      IDAT(3) = m                           $$ CURRENT ERROR ADDRESS
$$
11     PARAMS/'ENTER PROBE PARAMETERS', 8, $
          2, 'RAPID FEED', $
          2, 'ENTRY FEED'  $
          2, 'EXIT  FEED', $
          2, 'CLRNC DPTH', $
          2, 'RTRCT DPTH', $
          1, 'TOOL    # ', $
          1, 'OFFSET  # ', $
          1, 'ERR ADDRES', $
          IDAT(1), RDAT(1), STAT
      IF (STAT.EQ.0) GOTO 3          $$ REJECT
      IF (STAT.EQ.-1) GOTO 11        $$ O/C
$$
      FRA = RDAT(1)
      FEN = RDAT(2)
      FEX = RDAT(3)
      CCZ = RDAT(4)
      CRZ = RDAT(5)
      TNO = IDAT(1)
      TOS = IDAT(2)
      m   = IDAT(3)
$$
      SAVE FRA, FEN, FEX, CCZ, CRZ, TNO, TOS, REG
      GOTO 5
$$      END OF 10 MODALS
$$
20     CONT/
$$      START PROBE CYCLE
$$      •••••••••••••••••••••••••
$$
      GOPROB = PATTRN/RETRVE, 'goprobe', NOGRP, 0, 0, 0
      EXEKSF/'goprobe'
      EXEKSF/'dcsoff'
$$
      GOTO 5
$$      END OF 20 START PROBE CYCLE
$$
30     CONT/
$$      CALIBRATE PROBE CENTER
$$      •••••••••••••••••••••••••••••••••
$$
      SELECT/'INDICATE CIRCLE', 8, 1, CRCL(1), CNT, STAT
      OBTAIN/CRCL(1), 3, 6, RAD
      d = 2 * RAD
      SELECT/'INDICATE CIRCLE CENTER', 2, 1, PNT(1), CNT, STAT
      OBTAIN/PNT(1), 3, 1, X
      OBTAIN/PNT(1), 3, 2, Y
      OBTAIN/PNT(1), 3, 3, Z
$$
      RDAT(1) = DELZ
31     PARAMS/'START POINT FROM CIRCLE CENTER', 1, $
          2, 'DELZ START', $
          IDUM, RDAT(1), STAT
      IF (STAT.EQ.0) GOTO 5               $$ REJECT
      IF (STAT.EQ.-1) GOTO 31             $$ O/C
      DELZ = RDAT(1)
$$
```

```
      SAVE X, Y, Z, DELZ
      SAVE d
      EXEKSF/'center'
      GOTO 5
$$      END OF 30 CALIBRATE PROBE CENTER
$$
40     CONT/
:
:
:
:
$$      DATUM IN INTERNAL CORNER
$$      **********************************
$$
$$
      SELECT/'INDICATE A POINT ON THE CORNER', 2, 1, $
            PNT(1), CNT, STAT
      OBTAIN/PNT(1), 3, 1, X
      OBTAIN/PNT(1), 3, 2, Y
      OBTAIN/PNT(1), 3, 3, Z
$$
      RDAT(1) = DELX
      RDAT(2) = DELY
      RDAT(3) = DELZ
61     PARAMS/'START POINT FROM INDICATED POINT', 3, $
           2, 'DELX START', $
           2, 'DELY START', $
           2, 'DELZ START', $
           IDUM, RDAT(1), STAT
      IF (STAT.EQ.0) GOTO 5              $$ REJECT
      IF (STAT.EQ.-1) GOTO 61            $$ O/C
      DELX = RDAT(1)
      DELY = RDAT(2)
      DELZ = RDAT(3)
$$
      IDAT(1) = s                        $$ WOSET
      RDAT(1) = q                        $$ OVTRAV
62     PARAMS/'DATUM IN INTERNAL CORNER', 2, $
            1, 'WORK OFSET', $
            2, 'OVERTRAVEL', $
            IDAT(1), RDAT(1), STAT
      IF (STAT.EQ.0) GOTO 5              $$ REJECT
      IF (STAT.EQ.-1) GOTO 62            $$ O/C
      s = IDAT(1)
      q = RDAT(1)
$$
      XS = X + DELX                      $$ X START
      YS = Y + DELY                      $$ Y START
      ZS = Z + DELZ                      $$ Z START
      SAVE X, Y, Z, DELX, DELY, DELZ, XS, YS, ZS
      SAVE s, q
      EXEKSF/'icornr'
      GOTO 5
```

```
$$     END OF 60 DATUM IN INTERNAL CORNER
$$
70    CONT/
:
:
:
:
$$     MEASURE POCKET
$$     ************************
$$
      SELECT/'INDICATE A POINT ON FIRST SURFACE', 2, 1, $
            PNT(1), CNT, STAT
      OBTAIN/PNT(1), 3, 1, X1
      OBTAIN/PNT(1), 3, 2, Y1
      OBTAIN/PNT(1), 3, 3, Z1
$$
      SELECT/'INDICATE A POINT ON SECOND SURFACE', 2, 1, $
            PNT(2), CNT, STAT
      OBTAIN/PNT(2), 3, 1, X2
      OBTAIN/PNT(2), 3, 2, Y2
      OBTAIN/PNT(2), 3, 3, Z2
$$
      MENU/'MEASUREMENT DIRECTION', $
          'X AXIS*Y AXIS*', ISW, STAT
$$
      GOTO (91, 93), ISW
$$
91     CONT/                                $$ MEASUREMENT IN X
      RDAT(1) = DELY
      RDAT(2) = DELZ
92     PARAMS/'START POINT FROM FIRST INDICATED POINT', 2, $
           2, 'DELY START', $
           2, 'DELZ START', $
           IDUM, RDAT(1), STAT
      IF (STAT.EQ.0) GOTO 5                 $$ REJECT
      IF (STAT.EQ.-1) GOTO 92               $$ O/C
      DELY = RDAT(1)
      DELZ = RDAT(2)
      DELX = (X2 - X1)/2                    $$ POCKET CENTER IN X
      l = ABS(X2 - X1)                      $$ POCKET THICKNESS
$$
      GOTO 95
$$
$$
93     CONT/                                $$ MEASUREMENT IN Y
      RDAT(1) = DELX
      RDAT(2) = DELZ
94     PARAMS/'START POINT FROM FIRST INDICATED POINT', 2, $
           2, 'DELX START', $
           2, 'DELZ START', $
           IDUM, RDAT(1), STAT
      IF (STAT.EQ.0) GOTO 5                 $$ REJECT
      IF (STAT.EQ.-1) GOTO 94               $$ O/C
```

```
       DELX = RDAT(1)
       DELZ = RDAT(2)
       DELY = (Y2 - Y1)/2                    $$ POCKET CENTER IN Y
       l = ABS(Y2 - Y1)                      $$ POCKET THICKNESS
$$
       GOTO 95
$$
$$
95      CONT/
$$
       IDAT(1) = s                           $$ WORK OFSET (WOSET)
       IDAT(2) = t                           $$ TOOL OFSET (OSETNO)
       IDAT(3) = m                           $$ ERR ADRESS (ERRNO)
       RDAT(1) = h                           $$ TOLERANCE  (TLRNCE)
       RDAT(2) = q                           $$ OVERTRAVEL (OVTRAV)
       IDAT(4) = v                           $$ PRINT DIM  (PRTDIM)
$$
97      PARAMS/'ENTER PROBE PARAMETERS', 6, $
            1, 'WORK OFSET', $
            1, 'TOOL OFSET', $
            1, 'ERR ADDRES', $
            2, 'TOLERANCE ', $
            2, 'OVERTRAVEL', $
            1, 'PRINT DIM ', $
            IDAT(1), RDAT(1), STAT
       IF (STAT.EQ.0) GOTO 5                 $$ REJECT
       IF (STAT.EQ.-1) GOTO 97               $$ O/C
$$
       s = IDAT(1)
       t = IDAT(2)
       m = IDAT(3)
       h = RDAT(1)
       q = RDAT(2)
       v = IDAT(4)
$$
       XS = X1 + DELX                        $$ X START
       YS = Y1 + DELY                        $$ Y START
       ZS = Z1 + DELZ                        $$ Z START
       IF (ISW.EQ.1) Y1 = YS                 $$ MEASURE IN X
       IF (ISW.EQ.2) X1 = XS                 $$ MEASURE IN Y
       SAVE X1, Y1, Z1, DELX, DELY, DELZ, XS, YS, ZS
       SAVE s, t, m, h, q, v, l
       EXEKSF/'pocket'
       m = m +1                              $$ INCREMENT MEMORY ADDRESS
       GOTO 5
$$        END OF 90 MEASURE POCKET
$$
$$
       LINK/'PP'                             $$ LINK PP.dat
$$
       STOP
```

Program PP.dat:

```
$$      PROGRAM NAME: PP.dat (LINKED TO P.dat)
$$      ************************************************************
$$      PURPOSE: CREATES PROBING PROGRAMS
$$      INPUT: VALUES FOR PROBE PARAMETERS
$$      OUTPUT: VARIABLES' VALUES TO BE INCLUDED IN THE PROBE
$$           MACROS CALLED FROM WITHIN THE PROGRAM, USING
$$                     KEYSTRIKE FILES AND THE DISPLAY AND EDIT MODE.
$$      WRITTEN BY: ISRAEL GREENFELD, MAY 88
$$
      REFER/'P'                          $$ LINK TO P.dat
$$
100    CONT/
$$      MEASURE BOSS
$$      ******************
$$
      SELECT/'INDICATE CIRCLE', 8, 1, CRCL(1), CNT, STAT
      OBTAIN/CRCL(1), 3, 6, RAD
      d = 2 * RAD
      SELECT/'INDICATE CIRCLE CENTER', 2, 1, PNT(1), CNT, STAT
      OBTAIN/PNT(1), 3, 1, X
      OBTAIN/PNT(1), 3, 2, Y
      OBTAIN/PNT(1), 3, 3, Z
$$
$$
      RDAT(1) = DELZ
101    PARAMS/'START POINT FROM CIRCLE CENTER', 1, $
          2, 'DELZ START', $
          IDUM, RDAT(1), STAT
      IF (STAT.EQ.0) GOTO 5              $$ REJECT
      IF (STAT.EQ.-1) GOTO 101           $$ O/C
      DELZ = RDAT(1)
$$
      RDAT(1) = iz                       $$ DELZ TARGT (FEDTO)
      IDAT(1) = s                        $$ WORK OFSET (WOSET)
      IDAT(2) = t                        $$ TOOL OFSET (OSETNO)
      IDAT(3) = m                        $$ ERR ADRESS (ERRNO)
      RDAT(2) = h                        $$ TOLERANCE  (TLRNCE)
      RDAT(3) = r                        $$ RAD CLRNCE (RAPTO)
      RDAT(4) = q                        $$ OVERTRAVEL (OVTRAV)
      IDAT(4) = v                        $$ PRINT DIM  (PRTDIM)
      IDAT(5) = w                        $$ PRINT POS  (PRTPOS)
$$
102    PARAMS/'MEASURE BOSS', 9, $
          2, 'DELZ TARGT', $
          1, 'WORK OFSET', $
          1, 'TOOL OFSET', $
          1, 'ERR ADDRES', $
          2, 'TOLERANCE ', $
          2, 'RAD CLRNCE', $
          2, 'OVERTRAVEL', $
          1, 'PRINT DIM ', $
```

```
           1, 'PRINT POS ', $
           IDAT(1), RDAT(1), STAT
      IF (STAT.EQ.0) GOTO 5              $$ REJECT
      IF (STAT.EQ.-1) GOTO 102           $$ O/C
$$
      iz= RDAT(1)
      s = IDAT(1)
      t = IDAT(2)
      m = IDAT(3)
      h = RDAT(2)
      r = RDAT(3)
      q = RDAT(4)
      v = IDAT(4)
      w = IDAT(5)
$$
      SAVE X, Y, Z, DELZ
      SAVE iz, s, t, m, h, r, q, v, w, d
      EXEKSF/'boss'
      m = m +1                           $$ INCREMENT MEMORY ADDRESS
      GOTO 5
$$      END OF 100 MEASURE BOSS
$$
110    CONT/
:
:
:
:
$$      MEASURE XY SURFACE
$$      ************************
$$
      SELECT/'INDICATE A POINT ON THE SURFACE', 2, 1, $
            PNT(1), CNT, STAT
      OBTAIN/PNT(1), 3, 1, X
      OBTAIN/PNT(1), 3, 2, Y
      OBTAIN/PNT(1), 3, 3, Z
$$
      RDAT(1) = DELX
      RDAT(2) = DELY
      RDAT(3) = DELZ
131    PARAMS/'START POINT FROM INDICATED POINT', 3, $
           2, 'DELX START', $
           2, 'DELY START', $
           2, 'DELZ START', $
           IDUM, RDAT(1), STAT
      IF (STAT.EQ.0) GOTO 5              $$ REJECT
      IF (STAT.EQ.-1) GOTO 131           $$ O/C
      DELX = RDAT(1)
      DELY = RDAT(2)
      DELZ = RDAT(3)
$$
      IDAT(1) = s                        $$ WORK OFSET (WOSET)
      IDAT(2) = t                        $$ TOOL OFSET (OSETNO)
      IDAT(3) = m                        $$ ERR ADRESS (ERRNO)
      RDAT(1) = h                        $$ TOLERANCE  (TLRNCE)
      RDAT(2) = u                        $$ UPP TLRNCE (UPPTOL)
      RDAT(3) = q                        $$ OVERTRAVEL (OVTRAV)
      IDAT(4) = v                        $$ PRINT DIM  (PRTDIM)
$$
132    PARAMS/'ENTER PROBE PARAMETERS', 7, $
           1, 'WORK OFSET', $
           1, 'TOOL OFSET', $
           1, 'ERR ADDRES', $
           2, 'TOLERANCE ', $
           2, 'UPP TLRNCE', $
           2, 'OVERTRAVEL', $
           1, 'PRINT DIM ', $
           IDAT(1), RDAT(1), STAT
      IF (STAT.EQ.0) GOTO 5              $$ REJECT
      IF (STAT.EQ.-1) GOTO 132           $$ O/C
$$
      s = IDAT(1)
      t = IDAT(2)
      m = IDAT(3)
      h = RDAT(1)
      u = RDAT(2)
      q = RDAT(3)
      v = IDAT(4)
$$
      MENU/'MEASUREMENT DIRECTION', $
          'X AXIS*Y AXIS*', ISW, STAT
$$
      XS = X + DELX                      $$ X START
      YS = Y + DELY                      $$ Y START
      ZS = Z + DELZ                      $$ Z START
      IF (ISW.EQ.1) Y = YS               $$ MEASURE IN X
      IF (ISW.EQ.2) X = XS               $$ MEASURE IN Y
      SAVE X, Y, Z, DELX, DELY, DELZ, XS, YS, ZS
      SAVE s, t, m, h, u, q, v
      EXEKSF/'xysurf'
      m = m +1                           $$ INCREMENT MEMORY ADDRESS
      GOTO 5
$$      END OF 130 MEASURE XY SURFACE
$$
140     CONT/
$$      SPATIAL LOCATION OF PART
$$      *************************************
$$
      MENU/'PROBING PATTERN', $
          '6 POINTS - 3D*3 POINTS - 2D*', ISW, STAT
      IF (ISW.EQ.2) GOTO 141
      EXEKSF/'6points'
      GOTO 142
141    EXEKSF/'3points'
142    CONT/
      QUERY/'USE FUNCTION 12 IN Z AND 13 IN XY', RESP, STAT
      GOTO 5
```

```
$$      END OF 140 SPATIAL LOCATION OF PART
$$
150    CONT/
$$      SPECIAL FUNCTION
$$      ************************
$$
      GOTO 5
$$      END OF 150 SPECIAL FUNCTION
$$
$$
160    STOP
```

Appendix B: NC Post Processor Macros

This appendix contains three macros: goprobe.dat, boss.dat and xysurf.dat. Note the typical structure of motion to a start point, invokation of the gauging cycle and return to clearance plane. Note also the use of variables which are read from Anvil's run time library.

PPM goprobe.dat:

```
INSERT/'(PROBE CYCLE INITIATION)'
LOADTL/TNO, PROBE, OSETNO, TOS      $$ TOOL # AND OFFSET #
FEDRAT/FRA                          $$ RAPID FEEDRATE
FROM/0, 0, CRZ                      $$ RETRACT PLANE
GOTO/1, 1, CCZ                      $$ CLEARANCE PLANE
INSERT/'M01'
INSERT/'(END OF PROBE CYCLE INITIATION)'
```

PPM boss.dat:

```
INSERT/'(MEASURE BOSS)'
FEDRAT/FRA                          $$ RAPID FEEDRATE
GOTO/@PCX, @PCY, CCZ                $$ CURRENT X Y IN CLEARANCE PLANE
GOTO/X, Y, CCZ                      $$ X Y CIRCLE CENTER, Z CLEARANCE
FEDRAT/FEN                          $$ ENTRY FEEDRATE
GOTO/X, Y, Z+DELZ                   $$ START LOCATION
CYCLE/MEASUR, BOSS, DIAMTR, d, WOSET, s, OSETNO, t, ^
CYCLE/ERRNO, m, TLRNCE, h, RAPTO, r, OVTRAV, q, PRTDIM, v, PRTPOS, w
GOTO/X+d/2, Y, Z+iz                 $$ DUMMY MOTION TO TARGET
GOTO/X, Y, Z+DELZ                   $$ DUMMY RETURN TO START
FEDRAT/FEX                          $$ EXIT FEEDRATE
GOTO/X, Y, CCZ                      $$ RETURN TO CLEARANCE PLANE
INSERT/'M01'
INSERT/'(END OF MEASURE BOSS)'
```

PPM xysurf.dat:

```
INSERT/'(MEASURE XY SURFACE)'
FEDRAT/FRA                          $$ RAPID FEEDRATE
GOTO/@PCX, @PCY, CCZ                $$ CURRENT X Y IN CLEARANCE PLANE
GOTO/XS, YS, CCZ                    $$ X Y START ON CLEARANCE PLANE
FEDRAT/FEN                          $$ ENTRY FEEDRATE
GOTO/XS, YS, ZS                     $$ START LOCATION
CYCLE/MEASUR, XYSURF, WOSET, s, OSETNO, t, ERRNO, m, ^
CYCLE/TLRNCE, h, UPPTOL, u, OVTRAV, q, PRTDIM, v
GOTO/X, Y, ZS                       $$ DUMMY MOTION TO TARGET
GOTO/XS, YS, ZS                     $$ DUMMY RETURN TO START
FEDRAT/FEX                          $$ EXIT FEEDRATE
GOTO/XS, YS, CCZ                    $$ RETURN TO CLEARANCE PLANE
INSERT/'M01'
INSERT/'(END OF MEASURE XY SURFACE)'
```

Appendix C: Keystroke Files

A sample keystroke file is presented here. Note the use of various functions of the *display and edit* menu for appending the NC post processor macro to the probe path. The only difference between the various probe functions KSF's is the name of the macro to be inserted.

KSF bore.ksf:

```
88,02,10,0013,0033,1128,0787,1.1.1
2 ANVIL-5000 REL/REV 1.1.2 BY      MACHINING                17     000196
2 MACHINING                        DISPLAY AND EDIT         13     171086
7 SELECT TO    0.4361567535        3.0201361088              C     000261
4 ALLOW TOOLPATH(S) TO BE MODI                              OC     171264
2 DISPLAY AND EDIT N/C TOOL PA     ENTER LINE NUMBER        09     171265
3 LINE NUMBR =                     9999                  04 OC     171453
3 LINE NUMBR =                                           00 OC     171453
2 DISPLAY AND EDIT N/C TOOL PA     STEP BACKWARD            04     171265
2 DISPLAY AND EDIT N/C TOOL PA     INSERT LINES             10     171265
3 AFTER LINE =                                           00 OC     171455
2 SELECT INSERT MODE               N/C MACRO                07     171308
5 ENTER MACRO NAME                 bore                  06 OC     171319
2 SELECT INSERT MODE                                        OC     171308
2 DISPLAY AND EDIT N/C TOOL PA                              OC     171265
4 SAVE EDITED TOOLPATH?                                     OC     171268
6 SAVED TOOL PATH = TP0645                                  OC     171470
2 MACHINING                                                 OC     171086
2 ANVIL-5000 REL/REV 1.1.2 BY                                R     000196
2 ANVIL-5000 REL/REV 1.1.2 BY      SPECIAL FUNCTIONS        05     000196
2 SPECIAL FUNCTIONS/APPLICAT       KSF FILE MANAGE          09     050001
2 KEYSTROKE FILE MANAGE            TERMINATE KSF            02     050115
END OF KEYSTROKES
```

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